King County Watershed Modeling Services – Green River Water Quality Assessment, and Sammamish-Washington, Analysis and Modeling Program Watershed Modeling Calibration Report

In Progress

King County

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Section 5—Swamp Creek

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5 SWAMP CREEK MODEL DEVELOPMENT

5.1 SWAMP CREEK WATERSHED DOMAIN

The physical domain of the HSPF model for this study is the entire Swamp Creek watershed above the confluence with the Sammamish River, an area of approximately 24 square miles.

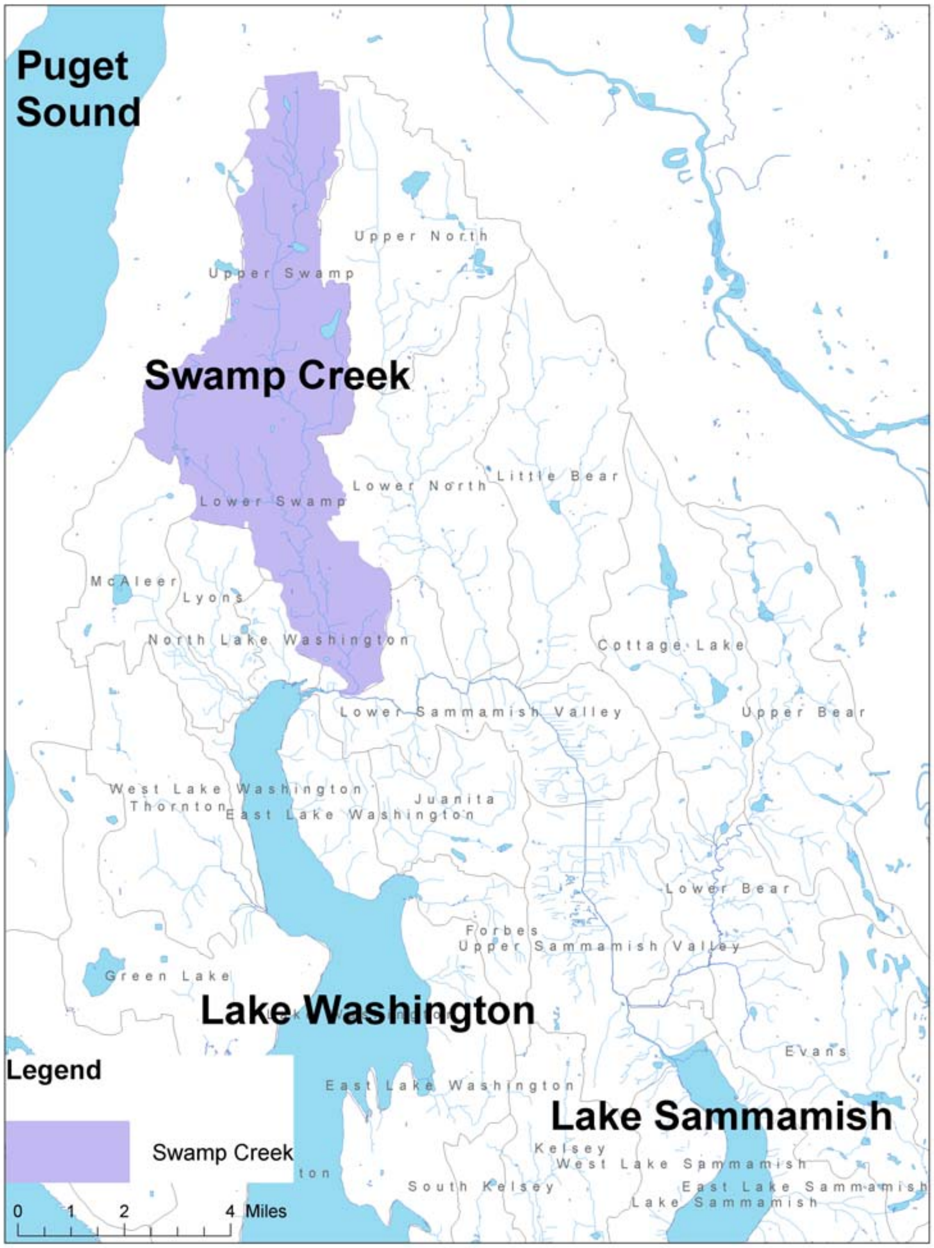


Figure 5.1-1 Swamp Creek Subbasin

5.2 DATA REQUIREMENTS AND AVAILABILITY

Database development is a major portion of the total modeling effort, requiring acquisition of data from a variety of sources, developing estimation procedures when needed data are not available, applying available techniques to fill-in missing data, and ensuring consistency and accuracy of the information obtained. Fortunately, for this study a database appears to exist to support the application. Historical data collected by King and Snohomish counties, the University of Washington, and various federal agencies (e.g., NOAA, NWS), supplemented with ongoing data collection efforts of these same groups, appears to provide a sound basis for the watershed modeling effort. The purpose of this section is to identify the data needs for the various models and present findings of the availability and sources of these data. Ultimately, the findings in this section will determine the timeframe and constituents the data are capable of supporting for model simulations.

5.2.1 OVERVIEW OF DATA NEEDS

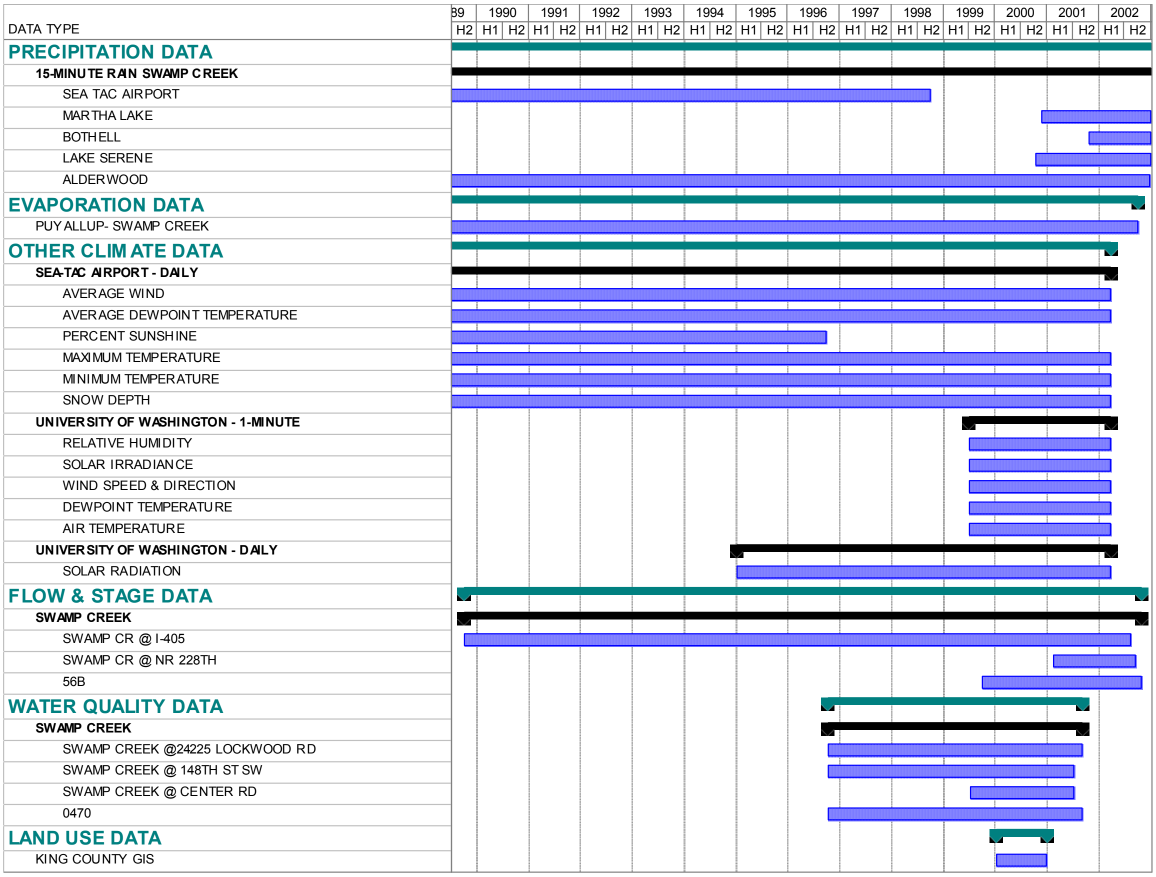
Within the modeling framework, the watershed model, HSPF, encompasses the largest spatial extent of the system, and will require the most encompassing dataset for model simulations. The data requirements for HSPF are extensive, in both spatial and temporal detail, especially for an application capable of assessing the potential environmental impact of such activities as land use development in the watershed based on GMA boundaries. Typical data requirements for an HSPF application can be categorized as input/execution data, watershed/channel characterization data, and calibration/validation data.

5.2.2 INPUT / EXECUTION DATA FOR MODEL SIMULATIONS

Input / execution data includes time series data that will drive the model simulations. For this application, the watershed model will require climatic data, point, import/export, diversion, and possibly atmospheric data. The output from HSPF will provide the input to CE-QUAL-W2.

The selection of the calibration and simulation periods requires an evaluation of what field data are available and a determination as to what additional data collection is needed to fully support the modeling effort. Table 5.2-1 provides a summary of the types of data that will be used as part of this modeling effort and the time periods over which they are available. These timelines are not intended to be all-inclusive but rather to provide an overall picture of available historical and current data. The references and sources used to develop the information in Table 5.2-1 include published reports (AQUA TERRA and King County, 2002b), USGS data, NOAA/NCDC data, the King County Hydrologic Information Center http://dnr.metrokc.gov/hydrodat/index.htm, and the Snohomish County Surface Water Management site http://www.co.snohomish.wa.us /publicwk/swm/, along with other personal communications and miscellaneous sources.

Table 5.2-1 Data Availability for Model Simulations



5.2.2.1 Calibration Data

Precipitation is the primary driving force in any watershed modeling effort. Evaporation is the other important climatic data required for hydrologic simulation.

Table 5.2-2 provides a summary of the types of data that will be used for the Swamp Creek hydrology calibration and the time periods over which they are available.

Table 5.2-2 Data Availability for Model Calibration

Location	Data Type	Time Step	Starting Date	Ending Date	DSN
Puyallup	Evaporation	Daily	1948/10/01	2002/09/30	1
SeaTac Airport	Precipitation	15-Minute	1948/10/01	1998/09/30	8
Martha Lake	Precipitation	15-Minute	2000/11/21	2003/01/15	101
Bothell	Precipitation	15-Minute	2001/10/17	2003/01/15	103
Lake Serene	Precipitation	15-Minute	2000/10/12	2003/01/10	105
Alderwood	Precipitation	15-Minute	1948/10/01	2002/12/23	113
Swamp Cr Gage	Streamflow	15-Minute	1999/10/01	2002/08/15	56

56B					
Swamp Cr nr 228th	Streamflow	15-Minute	2001/02/14	2002/09/18	228
Swamp Cr nr I-405	Streamflow	15-Minute	1988/08/11	2002/10/29	405

5.2.2.1.1 Precipitation

Precipitation data are available at a 15-minute interval from three King County gages and one Snohomish County gage for the time intervals shown in Table 5.2-2. The three King County gages (Martha Lake, Bothell, and Lake Serene) are located in Snohomish County and are part of King County's I&I data collection effort. The Bothell and Martha Lake gages are located in the Swamp Creek watershed, the Lake Serene gage is just west of the watershed. The Snohomish County gage (Alderwood) is located near the western boundary of the watershed. The locations of the respective King County gages and the one Snohomish County gage can be seen in Figure 5.2-1 Nearby Precipitation Stations.

Selection of the most applicable precipitation record to use for the calibration process was based on the length of the record, the time period of the record related to availability of recorded streamflow data, and the location of the precipitation station to the Swamp Creek watershed.

Only one long-term precipitation station is located in the Swamp Creek watershed. The specific location of the Swamp Creek precipitation station is at the Alderwood Water District yard near the intersection of Highway 99 and 148th Street SE. The gage record has been extended using disaggregated Everett NWS gage data.

As shown in Table 5.2-3 and Figure 5.2-1, the other nearby precipitation stations' records were compared based on annual total volumes to determine which record was most representative of the Swamp Creek watershed precipitation. Individual precipitation gages were considered for the calibration based on their location, length of record, and relationship to the PRISM isohyetals shown in Figure 5.2-1. Only the Alderwood precipitation record was found to accurately represent the entire Swamp Creek watershed for the calibration period of water years 1998 through 2002. The PRISM isohyets show increasing annual precipitation from west to east across the watershed, which is generally supported by the gage records. Because all of the Swamp Creek precipitation records are for very short periods, except the Alderwood gage, the isohyets were used as the primary reference in the determination of an appropriate multiplication factor (MFACT) by which the composite record was scaled to represent the entire Swamp Creek watershed.

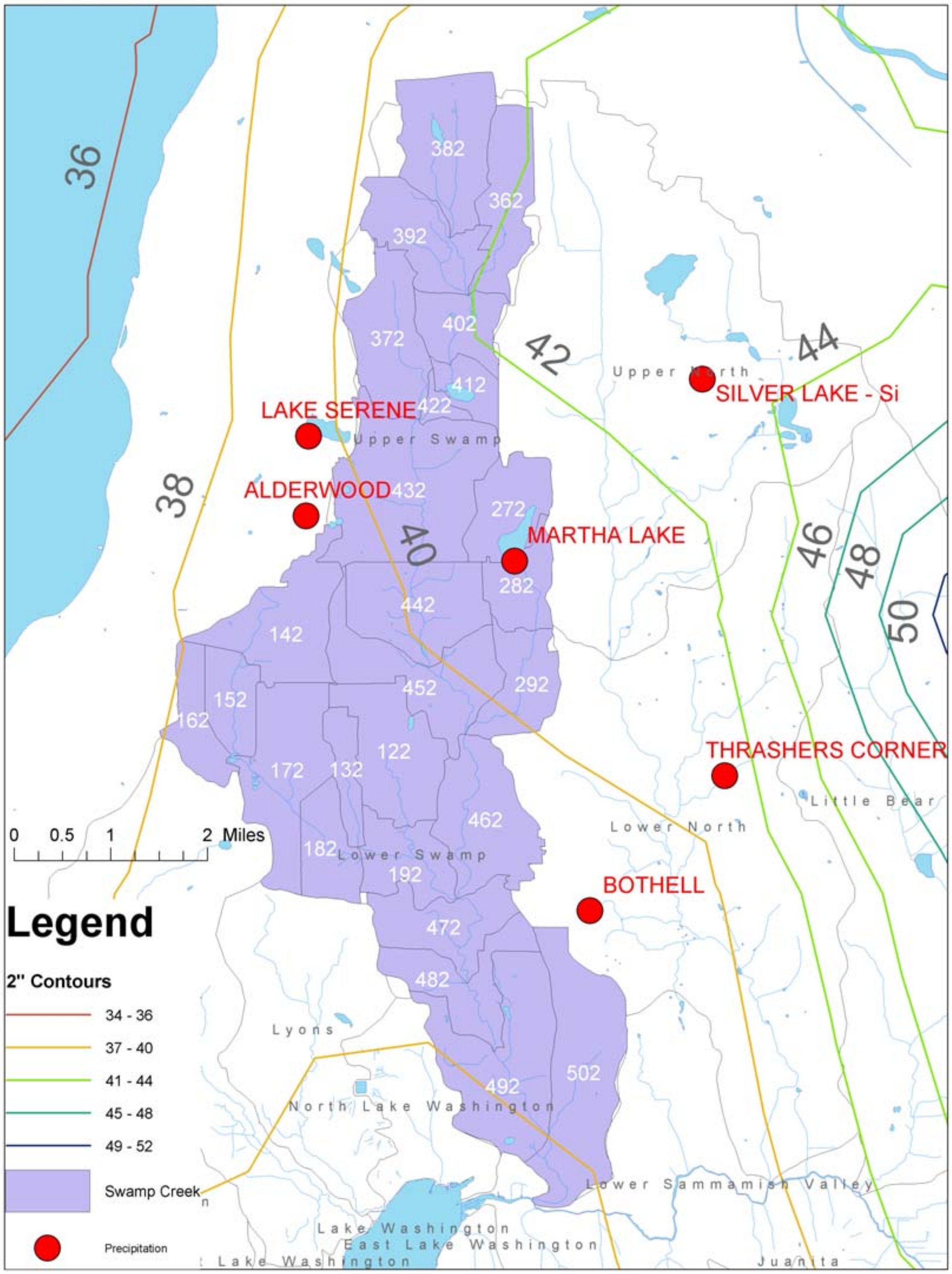
As a result the Alderwood precipitation record was used for the entire Swamp Creek watershed with two different multiplication factors to represent the long-term rainfall difference between the lower and upper portions of the watershed. MFACT was set to 1.10 for the lower watershed and 1.15 for the upper watershed.

Table 5.2-3 Comparison of Precipitation Annual Volumes

	King Co	King Co	King Co	Snohomish Co	
					Watershed
	Martha Lake	Lynnwood	L Serene	Alderwood	Average
Period	DSN 101	DSN 104	DSN 106	DSN 113	
2000/10	No Data	No Data	No Data	3.11	
2000/11	No Data	No Data	2.70	3.07	
2000/12	2.86	No Data	2.46	2.70	
2001/01	No Data	2.82	2.70	2.94	
2001/02	No Data	1.64	1.63	1.62	
2001/03	2.23	2.79	2.31	2.69	
2001/04	2.21	2.61	1.98	2.33	
2001/05	2.03	1.96	2.05	2.15	
2001/06	3.67	3.55	3.80	3.71	
2001/07	No Data	2.16	2.11	1.96	
2001/08	No Data	1.75	1.98	1.87	
2001/09	No Data	0.56	0.95	0.79	
2001/10	4.37	4.32	4.60	4.62	
2001/11	7.71	7.92	7.82	8.25	
2001/12	5.19	5.36	5.80	6.15	
2002/01	5.93	6.04	5.91	6.00	
2002/02	3.77	4.07	3.72	4.35	
2002/03	4.21	2.87	3.77	3.86	
2002/04	2.44	Missing Data	2.10	2.41	
2002/05	2.39	Missing Data	2.05	2.22	
2002/06	2.36	1.20	1.96	1.56	
2002/07	1.41	1.26	1.49	1.42	
2002/08	0.04	0.00	0.01	0.01	
2002/09	0.85	0.60	0.68	0.95	
2002/10	0.77	0.66	0.71	0.78	
2002/11	2.36	1.62	2.65	2.80	
2002/12	5.20	5.20	5.69	No Data	
WY 2002	40.67	34.54	39.91	41.80	

Period	King Co Martha Lake DSN 101	King Co Lynnwood DSN 104	King Co L Serene DSN 106	Snohomish Co Alderwood DSN 113	Watershed Average
PRISM at gage	41	39.4	39.5	39.5	
Long-term record				35.0	
Upper watershed					41.0
Lower watershed					38.5

The Alderwood precipitation record (DSN 113) was used for the calibration period of October 1997 through September 2002 (water years 1998-2002).



5.2.2.1.2 Figure 5.2-1 Nearby Precipitation Stations

5.2.2.1.3 Evaporation

The nearest evaporation data are available from Puyallup at the Washington State University Experimental Field Station. Puyallup lies approximately 60 miles to the south of the Swamp

Creek watershed, but because evaporation does not vary greatly in the Puget Sound lowlands this distance is not considered significant (Farnsworth, et al, 1982).

As shown in Table 5.2-2, the time period of the data is not a limiting factor for model simulations. The pan evaporation time series was developed from the available daily record for water years 1960 through 1997. For the most part, this station only measured pan evaporation during the growing season. Data for winter months were filled by King County staff (Hartley, 1999) using the Jensen-Haise equation. Data for water year 1960 were transposed without change to water years 1949 through 1959 and water years 1998 through 2002 (Hartley, 1999). The selection of a single year to represent years with missing data potentially introduces error in unusually wet or dry years. Accordingly, it may be worthwhile to instead use the Jensen-Haise equation for these years for which we do not have measured pan evaporation data. This will be investigated further.

Table 5.2-4 shows representative monthly evaporation volumes for water years 1981 through 2001. The volumes are relatively consistent from one year to the next. The average monthly values for water years 1960 through 1997 are summarized at the bottom of the table and have a mean annual total of 30.71 inches. The calibration period is based on water years 1999 through 2001 and, as described above, use the 1960 data. The mean annual total for the calibration period is 30.32 inches.

The evaporation data must be adjusted to convert to an estimate of potential evapotranspiration data that are used by the models. A pan evaporation coefficient is used to convert the pan evaporation data to PET data. For the Swamp Creek watershed this coefficient was set to 0.80, based on the pan evaporation coefficient values shown on Map 4 of the NOAA Technical Report NWS 33, *Evaporation Atlas for the Contiguous 48 United States* (Farnsworth, et al, 1982). The pan evaporation coefficient is often adjusted in the calibration process (Donigian, 2003), but there was no need to do so in the Swamp Creek calibration.

Table 5.2-4 Evaporation Monthly Volumes

Water Year	Oct (in)	Nov (in)	Dec (in)	Jan (in)	Feb (in)	Mar (in)	Apr (in)	May (in)	Jun (in)	Jul (in)	Aug (in)	Sep (in)	Total (in)
1981	1.11	0.72	0.65	0.90	0.84	1.74	2.64	2.86	3.24	4.88	4.86	2.98	27.42
1982	1.10	0.74	0.65	0.91	0.84	1.74	3.67	4.61	5.18	5.21	4.75	2.83	32.23
1983	1.73	0.74	0.65	0.90	0.84	1.74	3.04	4.11	4.47	4.02	4.93	2.71	29.88
1984	1.26	0.72	0.65	0.90	0.87	1.74	2.42	4.01	4.42	6.43	5.27	3.13	31.82
1985	1.40	0.91	0.28	0.35	0.67	1.99	2.37	4.13	4.93	7.56	5.41	2.72	32.72
1986	1.71	0.37	0.23	0.87	1.13	3.35	2.08	3.24	5.81	4.59	5.87	2.88	32.13
1987	0.95	0.44	0.40	0.41	0.80	1.13	2.39	4.25	5.67	4.88	5.44	3.64	30.40
1988	1.63	0.63	0.35	0.84	0.87	1.90	2.36	3.50	4.92	5.74	5.20	3.61	31.55
1989	1.24	0.69	0.61	0.84	0.83	1.77	3.32	5.84	5.33	6.20	5.13	3.95	35.75
1990	1.58	0.69	0.61	0.84	0.83	1.77	2.53	4.48	5.40	6.76	5.45	2.88	33.82
1991	1.31	0.69	0.61	0.84	0.83	1.77	2.53	3.79	3.92	6.40	6.20	3.63	32.52
1992	1.31	0.69	0.61	0.84	0.87	1.77	2.53	5.29	2.53	5.35	6.01	4.20	32.00
1993	2.57	1.19	0.87	0.34	0.46	0.42	0.51	4.17	1.96	5.34	6.33	4.37	28.53
1994	1.28	0.69	0.61	0.84	0.86	1.79	2.58	3.68	4.12	6.63	5.86	3.58	32.52
1995	1.28	0.69	0.61	0.84	0.84	1.77	2.53	5.29	2.53	5.35	6.01	4.20	31.94
1996	2.57	1.19	0.87	0.34	0.47	0.43	0.51	4.33	1.84	5.44	6.38	4.30	28.67
1997	2.57	1.19	0.87	0.34	0.46	0.42	0.51	4.17	1.96	5.34	6.33	4.37	28.53
1998	1.27	0.72	0.65	0.90	0.84	1.74	2.49	3.94	4.59	5.67	4.68	2.82	30.31
1999	1.27	0.72	0.65	0.90	0.84	1.74	2.49	3.94	4.59	5.67	4.68	2.82	30.31
2000	1.27	0.72	0.65	0.90	0.90	1.76	2.53	3.96	4.62	5.64	4.62	2.77	30.34
2001	1.25	0.72	0.66	0.90	0.87	1.76	2.53	3.96	4.62	5.64	4.62	2.77	30.30

Water Year	Oct (in)	Nov (in)	Dec (in)	Jan (in)	Feb (in)	Mar (in)	Apr (in)	May (in)	Jun (in)	Jul (in)	Aug (in)	Sep (in)	Total (in)
Average (60-97)	1.41	0.73	0.63	0.82	0.82	1.68	2.39	4.07	4.37	5.66	5.06	3.08	30.71
Average (99-01)	1.26	0.72	0.65	0.90	0.87	1.75	2.52	3.95	4.61	5.65	4.64	2.79	30.32

5.2.2.1.4 Water Quality Required Meteorological Data

AQUA TERRA identified the station at Everett Snohomish County Airport (Paine Field) as the best source of data for the first four of these quantities, and Seattle Sand Point Weather Station Forecast Office as the best source for solar radiation data. Table 5.2-5 contains selected descriptive attributes of these stations. The map in Figure 5.2-2 shows the spatial relation of these stations to the Swamp Creek watershed.

Table 5.2-5 Additional Meteorologic Data Stations for Swamp Creek

StationID	STATION NAME	COUNTY	LAT (dec^{o})	LONG (dec^{o})	ELEV (m)	START	END
452670	EVERETT AIRPORT	SNOHOMISH	47.900	-122.283	94.7	6/1/48	12/31/01
457470	SEATTLE SAND PT WSFO	KING	47.683	-122.250	18.3	3/21/95	12/31/02

Data from the Everett Airport were obtained from the Western Regional Climate Center (WRCC) which collects, processes, and sells data from observation stations that are part of the Automated Surface Observing System (ASOS). Unfortunately, the data for Everett had not been processed and were delivered in “raw” format. AQUA TERRA processed the files in order to standardize the time interval and quantify the cloud cover estimations.

The time interval is hourly with the observation time in the last 10 minutes of the hour preceding that represented by the date and time labels. There were intermittent periods of missing data that were filled either by interpolation or by weighting values from nearby stations from the same time interval. For temperature and dew point, values were interpolated if there were 8 or fewer consecutive missing values. For cloud cover and wind, values were interpolated if there were 24 or fewer consecutive missing values. When filling longer gaps using data from nearby stations, the values were weighted by a factor equal to the ratio of the means at the two stations over the period of interest. Additionally, wind values were normalized from the anemometer height to a height of 2 feet.

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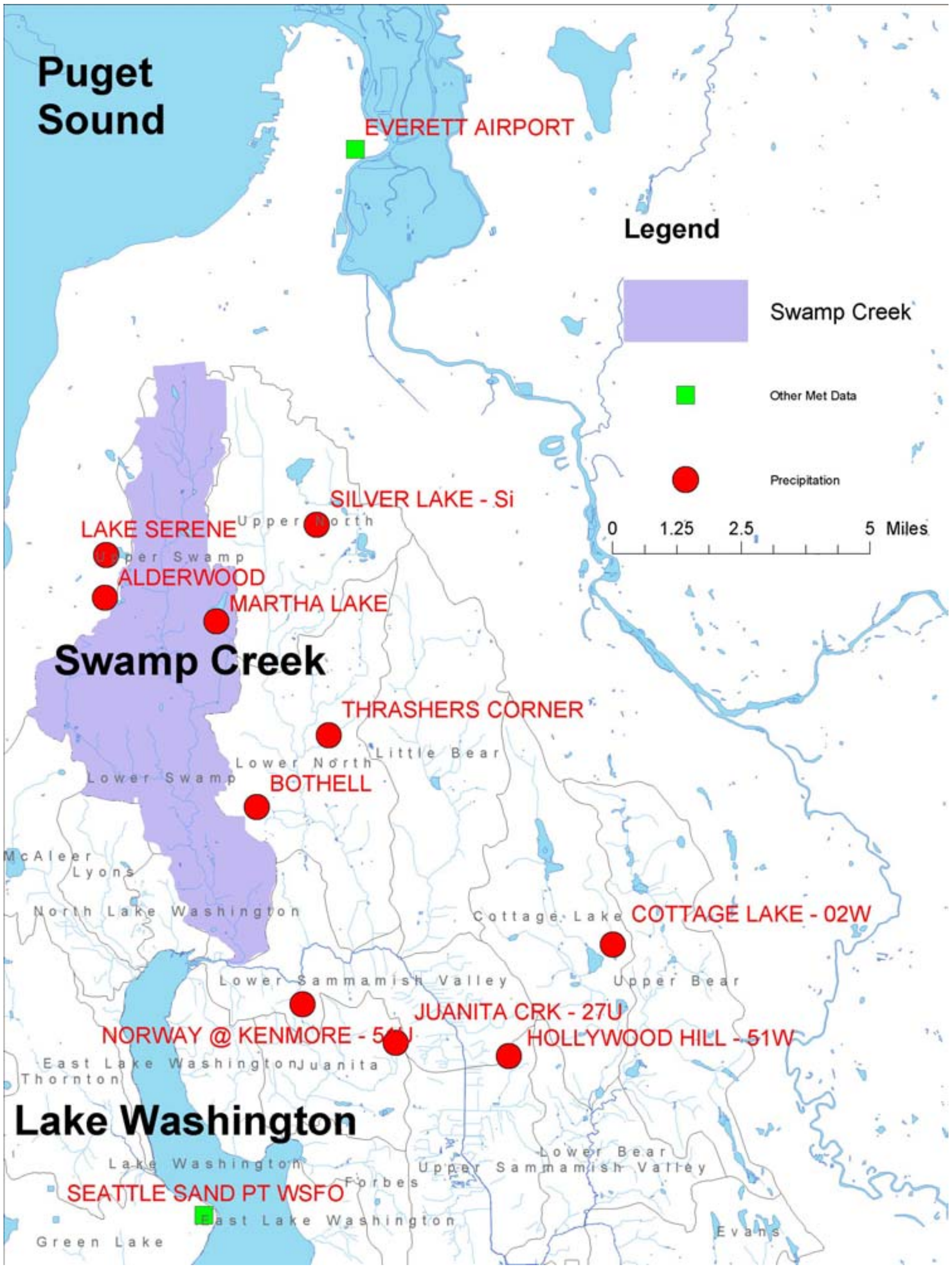


Figure 5.2-2 Map of Meteorologic Data Stations Used for Swamp Creek

Cloud cover was recorded at one or more ceilings with a verbal description of CLR, FEW, SCT, BKN, or OVC. ASOS defines these terms as:

Table 5.2-6 ASOS Terms

Term	Description	Equivalent in Octas	Avg Decimal Equivalent
CLR	Clear	0/8	0.0

FEW	Few	1/8 to 2/8	0.1875
SCT	Scattered	3/8 to 4/8	0.4375
BKN	Broken	5/8 to 7/8	0.75
OVC	Overcast	8/8	1.0

HSPF requires a value of 0-10 to describe the degree of cloud cover; therefore, an algorithm was used to transform the descriptions to a numeric value in this range. For the first reported ceiling, the average decimal equivalent was multiplied by 10 and taken as the total cloud coverage. If additional ceilings were reported, an incremental increase in total coverage was calculated in the same manner, but was then multiplied by the fraction of remaining uncovered sky.

Solar radiation data were collected as part of the Integrated Surface Irradiance Study (ISIS) conducted by the Air Resources Laboratory, which operates the National Oceanic & Atmospheric Administration's national broadband solar radiation network. Measurements of shortwave global horizontal radiation were recorded every 15 minutes, so these values were aggregated into hourly values. Missing data were filled by estimating solar radiation from the cloud cover using the 'Compute' tool in WDMUtil. The algorithms contained in this tool use the hourly or daily average cloud cover to attenuate theoretical maximum daily solar radiation at the ground, which is generated as a function of latitude and Julian date. The resulting total daily radiation is distributed over the daylight hours, which are also computed from latitude and Julian day.

5.2.2.1.4.1 Additional Water Quality Source Data

In addition to nonpoint loadings, other sources and losses of water quality constituents that must be represented in a model of this type are point sources, imports, diversions, and atmospheric deposition. There were no point sources or diversions identified in Swamp Creek. Therefore, neither of these quantities are considered in the water quality budget of Swamp Creek. Time series of nitrate and ammonia concentrations in rainfall (atmospheric deposition) were incorporated into the model using the standard methodology for specifying atmospheric deposition in HSPF. The concentrations from the two closest National Atmospheric Deposition Program (NADP) monitoring stations were averaged and combined with the rainfall data to produce loadings of nitrate and ammonia to the surface storages on land segments. The two NADP stations are LaGrande (Pierce County) and North Cascades National Park (Skagit County).

5.2.3 WATERSHED / CONVEYANCE SYSTEM CHARACTERIZATION DATA

Information describing the characteristics of the watershed, including topography, drainage patterns, meteorological variability, soils conditions, and the land use distribution are required for segmenting the watershed into individual land segments that demonstrate a similar hydrologic and water quality response. A wealth of GIS data is available from King County to describe the aforementioned characteristics of the watershed. In addition, the region has been modeled extensively using HSPF for hydrology applications which have resulted in a database of HSPF calibration parameters as they relate to watershed characteristics.

In an analogous fashion, information describing the channels, floodplain morphology, culverts, and other hydraulic features within the watershed allows for the segmentation of the conveyance system (both natural and artificial) into discrete sections with similar hydraulic and water quality behavior. Locations of dams/reservoirs, point source discharges, gages/data collectors, culverts, and diversions provides information to develop a segmentation scheme that supports modeling localized conditions within the watershed.

Table 5.2-7 documents the various information, along with the respective sources, that was used in characterizing the watershed and conveyance system. The use of this information will be discussed in detail in Section 5.2.4.2.

Table 5.2-7 Data and GIS Coverages used for Characterization of the Watershed and Conveyance System.

Data / GIS Coverage	Source	Comment
Digital Elevation Model (DEM)	USGS	Required 4 individual 10 meter resolution DEMs to be mosaiced together
Slopes	AQUA TERRA Consultants	Developed using DEM and ArcView Spatial Analyst functionality
Land Use	King County	
Soils	King County, AQUA TERRA Consultants	Coverage modified to group soils into following 4 classes: till, outwash, saturated, and bedrock
Hydrography/Stream Network	King County	Swamp Creek and major tributaries
Stream and Meteorological Gages	King County, Snohomish County, NOAA	Locations of King and Snohomish County and nearby NOAA gages
Culverts	Snohomish County	Locations and attributes of culverts within the Swamp Creek watershed; supplemented by field survey*
Cross-sections	Snohomish County	Field survey*

* Information provided from the Snohomish County Drainage Needs Report hydraulic modeling.

5.2.4 CALIBRATION / VALIDATION DATA

The hydrologic calibration and subsequent validation of a watershed model requires observed flow. Table 5.2-1 and the following sub-sections reflect knowledge of known monitoring that has been performed in Swamp Creek. The stations discussed in the following sections are displayed in Figure 5.2-3.

5.2.4.1 Streamflow

Recorded streamflow data are used to check the simulated streamflow results and evaluate the accuracy of the calibration. There are currently three streamflow stations along the Swamp Creek that are actively collecting data. All three of these gages (one operated by King County and two by Snohomish County) have been in operation long enough to develop an accurate rating curve.

Of the three gages the one in longest operation is the Swamp Creek gage near the I-405 overpass and Filbert Road. This gage has a rating curve, is located just upstream of the confluence with Martha Creek, and has been collecting data since August 1988. The hydrology calibration focus on the period of October 1998 through September 2002 to be consistent with the land use data.

Recorded streamflow data are complete at this station for the period of October 1997 through September 2002. Maximum flow events for each water year are shown in Table 5.2-8. Each maximum flood event occurred in the autumn or winter in response to large rainfall events, except for water year 2001 (which did not have any large winter storms).

Table 5.2-8 Swamp Creek Maximum Streamflows at Gage near I-405

Water Year	Maximum Flow (cfs)	Date of Event
1998	216	1998/01/23
1999	180	1999/02/25
2000	176	1999/11/12
2001	54	2001/06/11
2002	408	2001/12/17

For this same period of record low flows at this gage less than 1 cfs.

The second Snohomish County gage is located near 228th Street SW and Locust Road. It has a shorter period of record than the gage near I-405. It started operation on 14 February 2001. Due to its short period of record this gage was used as a check on the calibration, but with less emphasis than the I-405 gage with its longer record. At this gage observed flows ranged from 3 to 500 cfs.

There is also the King County stream gage 56B near 192nd Street NE. At this gage the period of record started in October 1999. This is the most downstream gage. Flows at this gage ranged from 6 to 600 cfs and were also used in the calibration.

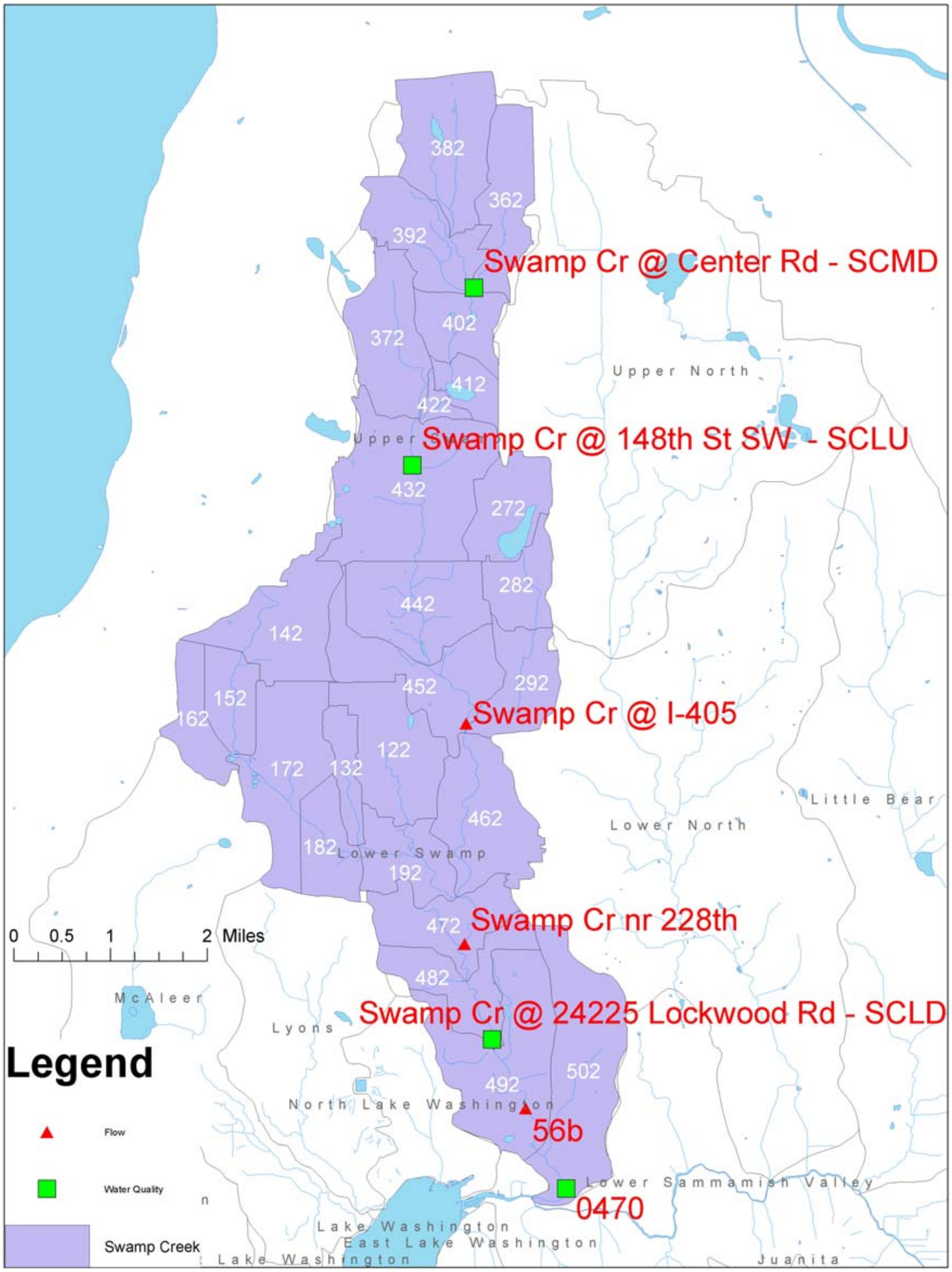


Figure 5.2-3 Flow and Water Quality Gages

5.2.4.2 Water Quality Calibration Data

Four long term water quality sampling sites were identified within the Swamp watershed. The first is sampled by King County, and data for that station were provided directly from the County. Snohomish County samples at three other stations, and data for these were obtained from the Snohomish County Surface Water Management (SWM) online data application at http://198.238.192.103/spw_swhydro/geo-search.asp.

The map in Figure 5.2-4 shows the spatial relation of the stations to the study area. All stations are located on Swamp Creek.

The outlet station in King County (Station 0470) has data for many of the constituents of interest, and is the primary calibration station for the watershed. The three Snohomish County stations have data for only total phosphorus, nitrate, dissolved oxygen, TSS, temperature, and pH. Since there are few or no direct measurements of organic material (BOD, total organic carbon, dissolved organic matter, etc), the calibration of organics was based on the apparent organic N and P values inferred from measured total N, total P, and the inorganic nutrient forms (i.e., nitrate, ammonia, and orthophosphate).

For purposes of comparing values during calibration, the values observed at a particular sampling station are compared to those simulated in the reach on which that station is located, unless the station is located just downstream from a reach outlet in which case the values are compared against those from the upstream reach. Using this reasoning, the following stations are compared against the corresponding reaches:

Table 5.2-9 Linkage of Sampling Station to Reach Number

Station	Reach
Swamp Cr @ Center Road (SCMD)	362
Swamp Cr @ 148th Street SW (SCLU)	432
Swamp Cr @ 24225 Lockwood Road (SCLD)	482
Swamp Creek @ Station 0470	502

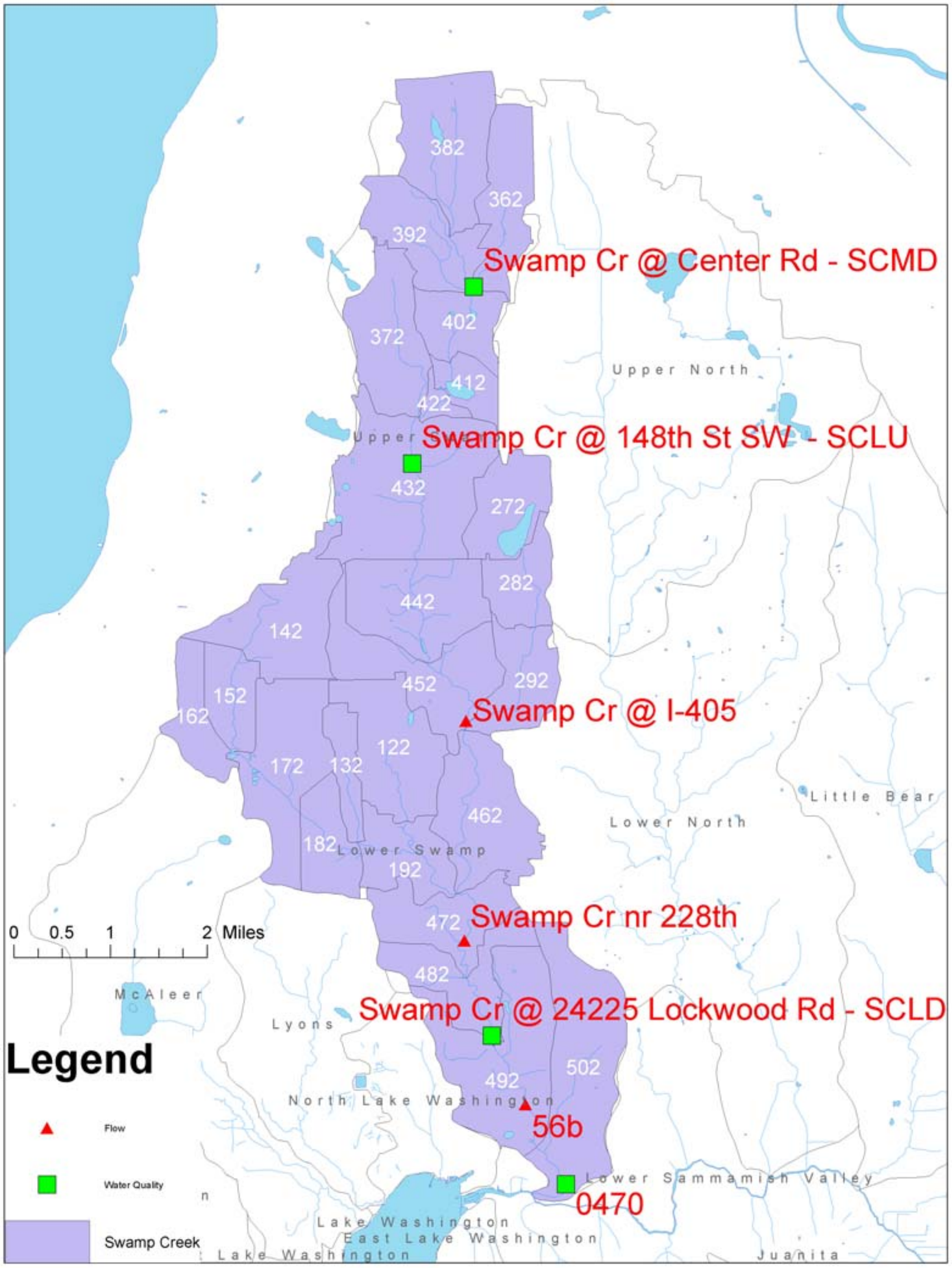


Figure 5.2-4 Map of Water Quality Data Stations Used for Swamp Creek

All four stations are typically sampled on a monthly interval. Table 5.2-10 summarizes the period of record for the various constituents sampled at each station.

Table 5.2-10 Constituents and Periods of Record for Water Quality Monitoring Stations on Swamp Creek

Constituent	Stations Center Road (SCMD)	148th Street SW (SCLU)	Lockwood Road (SCLD)	Station 0470
Water Temperature	7/19/99-7/12/01	8/2/93-7/12/01	10/14/92-9/10/01	1/11/93-9/10/01
Dissolved Oxygen	7/19/99-7/12/01	10/14/92-7/12/01	10/14/92-9/10/01	1/11/93-9/10/01
BOD				
Suspended Sand				
Suspended Silt				
Suspended Clay				
Total Suspended Sediment	7/19/99-7/12/01	5/19/94-5/3/01	8/2/93-6/7/01	1/11/93-9/10/01
Ammonia / Ammonium				1/11/93-9/10/01
Nitrite / Nitrate	10/5/92-7/12/01	10/14/92-7/12/01	10/14/92-9/10/01	1/11/93-9/10/01
Organic Nitrogen				
Total Nitrogen				4/12/93-9/10/01
Phosphate				1/11/93-9/10/01
Organic Phosphorus				
Total Phosphorus	10/5/92-7/12/01	10/14/92-7/12/01	10/14/92-9/10/01	1/11/93-9/10/01
Total Organic Carbon				1/11/93-9/10/01
Total Inorganic Carbon				
Alkalinity				5/12/97-9/10/01
pH	10/5/92-7/12/01	10/14/92-7/12/01	10/14/92-9/10/01	
Silica				
E-Coli				10/21/98-9/10/01
Benthic Algae				

5.2.4.3 WATERSHED SEGMENTATION AND CHARACTERIZATION

Whenever HSPF, or any watershed model, is applied to an area of any significant size, the entire study area must undergo a process referred to as segmentation. The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, which are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation then provides the basis for assigning similar or identical parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a segment. Since HSPF and most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area.

The initial segmentation typically involves delineating areas (catchments) that have similar meterological conditions, topographical features, use practices for a given land, and/or are a region of interest (e.g., NPS loads need to be quantified). Once the catchments and channel segments have been defined, these catchments must then be further characterized to: 1) develop the model categories (i.e., PERLNDs / IMPLNDs) to represent; 2) define the physical parameters (e.g., elevation, slopes, channel length) for HSPF using available data; and 3) establish initial calibration parameters for HSPF based on past applications within the region and past experience with the model.

5.2.4.3.1 Catchment Delineation

The initial catchment delineation was performed as part of the Snohomish County Drainage Needs Report study (RW Beck, 2002). It was revised by AQUA TERRA Consultants to consolidate numerous small catchment areas into 26 catchments ranging in size from 0.11 to 2.16 square miles (Table 5.2-11). The catchments are shown in Figure 5.2-5; the schematic in **Error! Reference source not found.**.

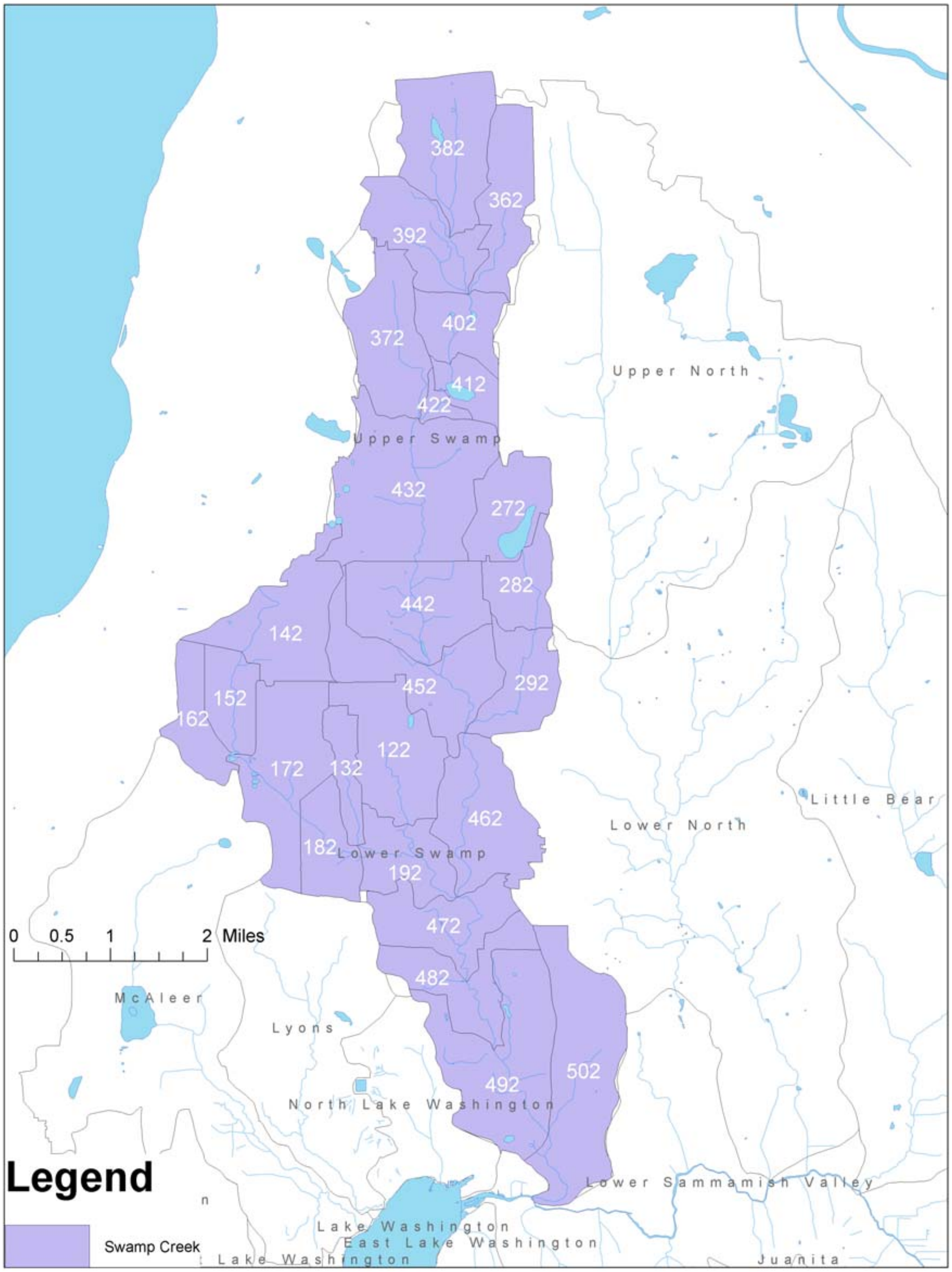
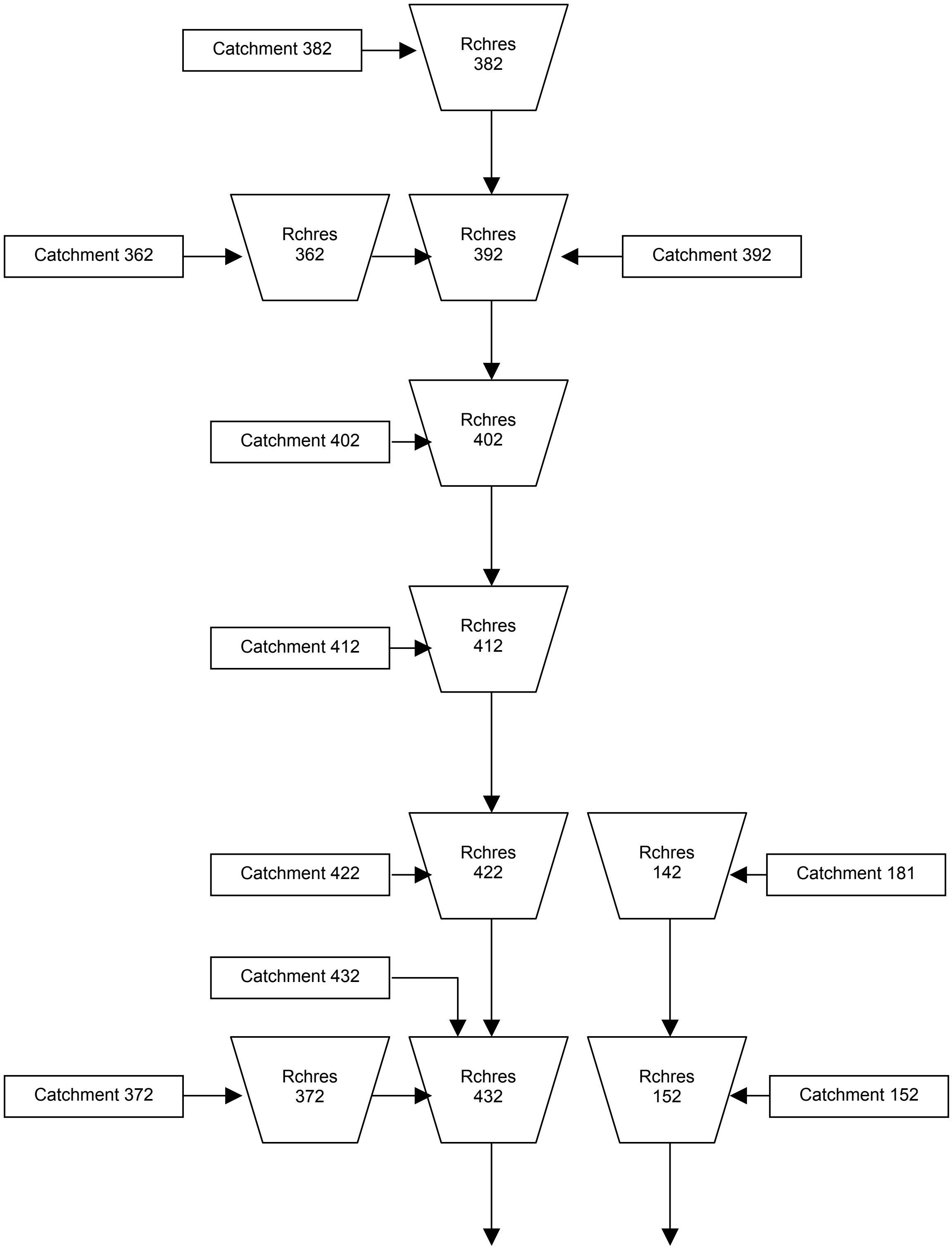


Figure 5.2-5 Swamp Creek Catchments

Table 5.2-11 Catchment Areas

Catchment No.	Catchment Area (acres)	Stream Reach No.
122	743	122
132	230	132
142	685	142
152	335	152
162	334	162
172	859	172
182	388	182
192	445	192
272	439	272
282	353	282
292	457	292
362	563	362
372	682	372
382	818	382
392	555	392
402	376	402
412	201	412
422	76	422
432	1383	432
442	796	442
452	776	452
462	799	462
472	558	472
482	528	482
492	1147	492
502	1150	502


Catchment 382
Rchres 382
Catchment 362
Rchres 362
Rchres 392
Catchment 392
Catchment 402
Rchres 402
Catchment 412
Rchres 412
Catchment 422
Rchres 422
Rchres 142
Catchment 181
Catchment 432
Catchment 372
Rchres 372
Rchres 432
Rchres 152
Catchment 152

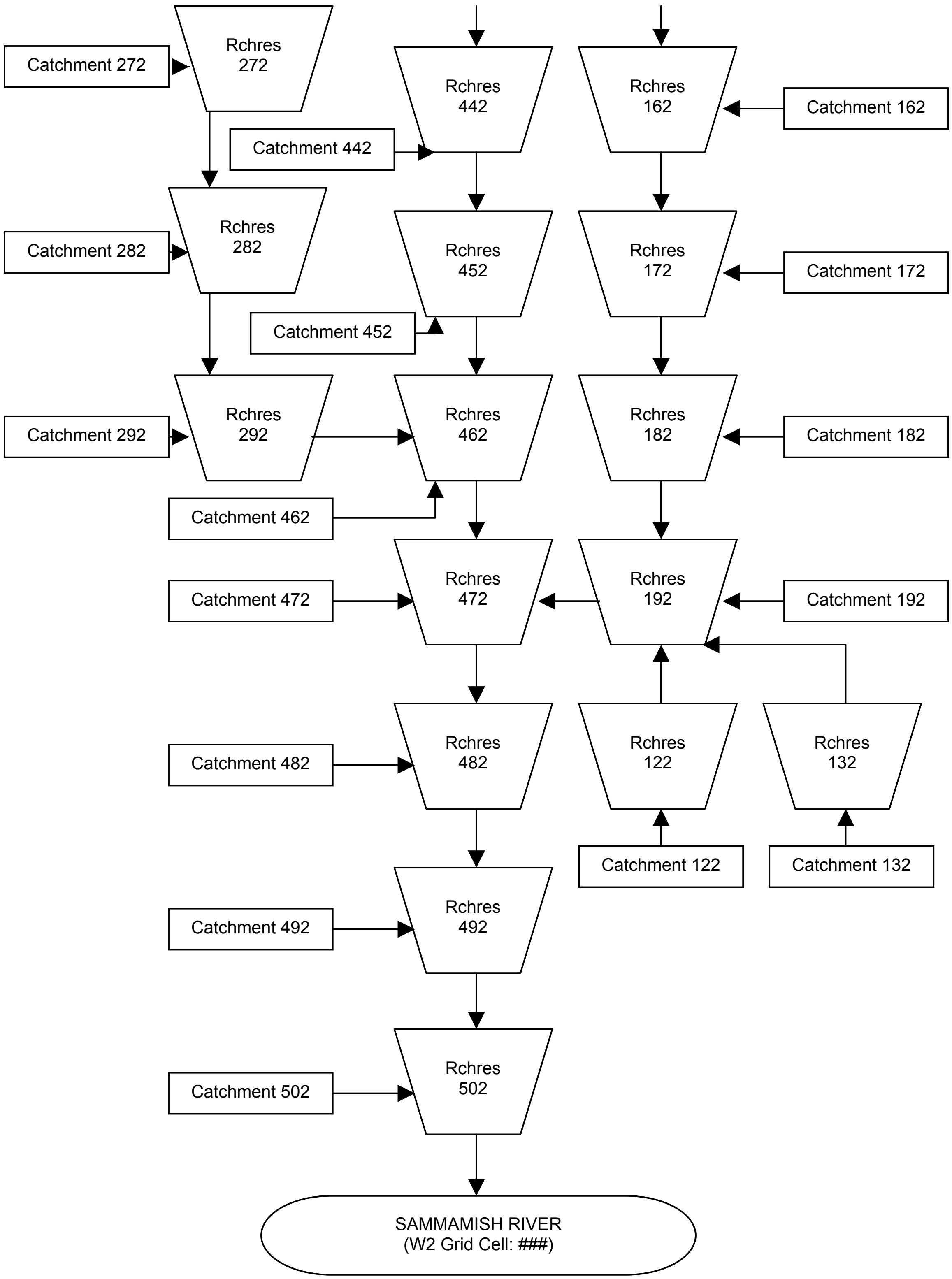


Figure 5.2-6 Swamp Creek Schematic

5.2.4.3.2 PERLND and IMPLND Categories

After the catchment delineation was finalized, the areas of the respective PERLND (pervious land) and IMPLND (impervious land) categories were determined on a catchment-by-catchment basis. Land categories are selected so that a given set of parameters represents the hydrologic and water quality response from that land category.

For an application involving water quality simulation, such as the Swamp Creek application, it is also necessary to consider how the use practices for various land uses impact the nonpoint source loadings. For this application, this involves increasing the number of vegetation/land use categories that are represented by the model. The PERLND / IMPLND categories were developed based on the following revised scheme.

1. soils: till, outwash, saturated, bedrock
2. vegetation/land use: forest, pasture/agricultural, cropland, forest residential, low density residential landscaping, high density residential landscaping, commercial/industrial landscaping
3. land slope: flat (0-5%), low (5-10%), medium (10-15%), steep (>15%)

It was determined that outwash and saturated soils could be grouped for all land slope categories (i.e., flat, low, medium, and steep); the slopes for these soils are not expected to vary significantly. Thus, the hydrologic and water quality responses from these areas are not expected to be greatly impacted by slope differences. Saturated and bedrock soils are insignificant in the Swamp Creek watershed and are not included in the HSPF model.

For modeling purposes a distinction is made between total impervious area and effective impervious area. Total impervious area includes all surfaces that do not infiltrate runoff. Roofs, paved streets, sidewalks, driveways, and parking lots are all part of the total impervious area. Effective impervious area (EIA) is defined as the area where there is no opportunity for surface runoff from an impervious site to infiltrate into the soil before it reaches a conveyance system (pipe, ditch, stream, etc.). Because it is extremely expensive and time consuming to look at every impervious surface in a watershed to determine whether or not it is an effective impervious area, average EIA values are used instead. Each average EIA value is based on the land use (forest, low density residential, high density residential, commercial, etc.) and previous experience in other Puget Sound lowland watersheds. For example, the following EIA percentages in Table 5.2-12 are representative values that have been provided by King County (Burkey, 2002). Other continuous simulation models use similar schemes to separate out impervious areas from pervious. These land use categories in Table 5.2-12 can also be used to differentiate different land covers and pollutant sources.

Table 5.2-12 HSPF EIA Values

King County Land Use Categories	Forest	Pasture	Forest Residential	Low Density Residential	High Density Residential	Commercial/ Industrial	Road
	%	%	%	%	%	%	%
Forest	0	0	0	0	0	0	0

King County Land Use Categories	Forest	Pasture	Forest Residential	Low Density Residential	High Density Residential	Commercial/ Industrial	Road
Recently cleared	0	0	0	0	0	0	0
Scrub/shrub	0	0	0	0	0	0	0
Grass – brown	0	0	0	0	0	0	0
Grass – green	0	0	0	0	0	0	0
Developed low	0	0	0	5	0	0	0
Developed med	0	0	0	0	25	0	0
Developed high	0	0	0	0	0	50	0
Bare ground/asphalt	0	0	0	0	0	50	0
Bare rock/concrete	0	0	0	0	0	0	50
Shadow	0	0	0	0	0	0	0
INSIDE=100	0	0	0	0	0	0	86

Corresponding pervious land divisions are shown below in Table 5.2-13.

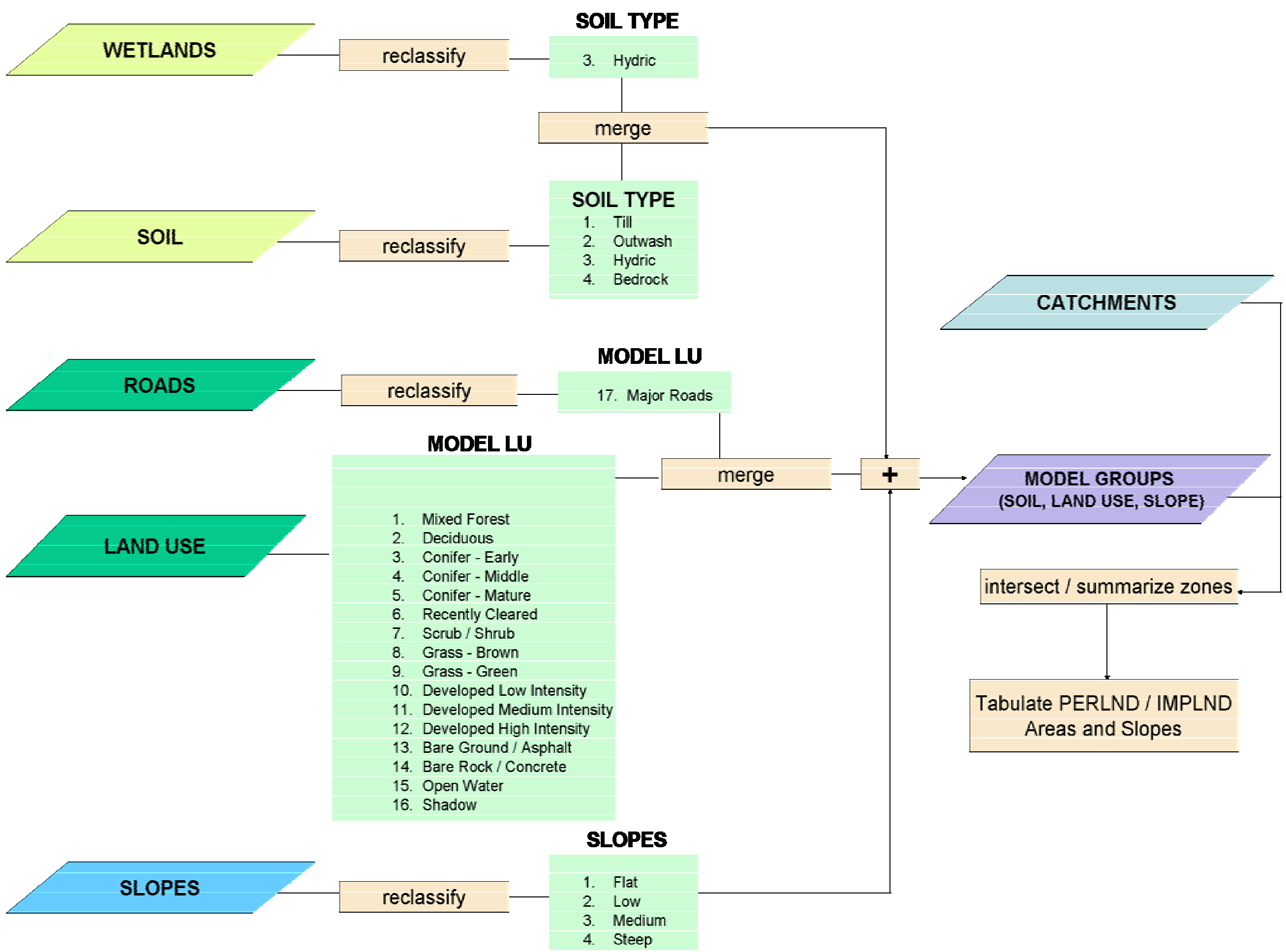
Table 5.2-13 HSPF Pervious Land Divisions

King County Land Use Categories	Forest	Pasture	Forest Residential	Low Density Residential	High Density Residential	Commercial/ Industrial	Road
	%	%	%	%	%	%	%
Forest	100	0	0	0	0	0	0
Recently cleared	0	100	0	0	0	0	0
Scrub/shrub	F*	100-F	0	0	0	0	0
Grass – brown	0	100	0	0	0	0	0
Grass – green	0	0	0	100	0	0	0
Developed low	0	0	35	60	0	0	0
Developed med	0	0	0	0	75	0	0
Developed high	0	0	0	0	0	50	0
Bare ground/asphalt	0	0	0	0	50	0	0
Bare rock/concrete	0	0	0	0	0	50	0
Shadow	50	50	0	0	0	0	0
INSIDE=100	0	0	0	0	0	14	0

* The percent F (forest) is based on the percentage of forest in the catchment compared to pasture.

For the purpose of the Swamp Creek simulation it is assumed that pasture is the same as agricultural animal (hobby farm) land use. The other pasture-related category of cropland may be used in other parts of the SWAMP and Green WQA study areas.

Determining the areas of the PERLNDs / IMPLNDs within the catchments is readily handled within the framework of a GIS system (ArcView) with some additional processing using Microsoft Access. Figure 5.2-7 displays a flow chart describing the methodology for spatially and quantitatively defining the PERLND / IMPLND categories. The catchment and soil coverages will be intersected in order to quantify the areas of various soil types within a given catchment. The resulting coverage will then be reclassified to group soils into till, outwash, saturated soils, and bedrock. Table 5.2-14 displays the relationship between the King County attribute geologic code to the four reclassified soil types. The land use coverage was reclassified into the vegetative/land use categories previously discussed and intersected with the modified soils coverage; creating regions with the desired combinations of soil type and vegetation characteristics (e.g., TF – Till, Forest).



Legend: **Soil Type** –Till; Outwash; Hydric; Bedrock
LU – Mixed Forest; Decidious; Conifer Early; Conifer Middle; Conifer Mature; Recently Clear; Scrub/Shrub; Grass Brown; Grass Green; Developed Low; Developed Medium; Developed High; Bare Ground Asphalt; Bare Ground Concrete; Open Water; Shadow
Slope – Flat (0 – 5%); Low (5-10%); Medium (10-15%); Steep (>15%)

Figure 5.2-7 PERLND / IMPLND Development

Table 5.2-14 King County Geologic Code to Four Soil Types

SOIL TYPE			
Till	**Outwash**	**Saturated**	**Bedrock**
Qmw	Qb	Qls	Tb
Qoal	Qal	Qw	Tdg
Qob	Qag		Teg
Qpf	Qf		Tf
Qt	Qva		Ti
Qtb	Qvi		Tmp
Qtu	Qvr		To
Qu	Qyal		Tp
Qvb			Tpr
Qvp			Tpt
Qvt			Ts
Qvu			Tsc
M			Tsg
Qom			Tv

Using the 10-meter resolution DEM, percent slopes were developed for the watershed at the same resolution. The zones established by the desired combinations of soil type and vegetation were then summarized using this slope grid (i.e., the weighted average slope for each polygon was assigned). These slopes were reclassified into flat, low, medium, and steep classifications based on the ranges discussed earlier (e.g., TFF – Till, Forest, Flat)

The final processing occurred outside the GIS within Microsoft Access. At this point, the multiple slope classes for outwash and saturated soils and the vegetation classes with an impervious component were combined into one slope class. In addition, the EIA was broken out from these vegetation classes to create four IMPLND categories (i.e., residential, commercial, industrial, and major road pollution) using the values and method previously presented in Table 5.2-11 and accompanying discussion. Table 5.2-15 presents the final potential 72 PERLND / IMPLND categories; not all categories exist in Swamp Creek watershed. GIS processing identified the specific categories needed.

The final processing produced a spreadsheet with the number of acres for each PERLND and IMPLND in each catchment. Within each catchment the relative size of the PERLND was checked. If the PERLND consisted of less than 5 percent of the catchment area then it was aggregated to an adjacent larger PERLND according to rules developed by AQUA TERRA Consultants. The purpose of the aggregation was to minimize the number of PERLNDs per catchment for water quality simulation linkages. Physically this also means that very small PERLNDs probably do not have a direct connection to the catchment's stream reach (RCHRES), but drain through an adjacent, larger PERLND. IMPLND areas were not changed.

Table 5.2-15 Final PERLND/IMPLND Categories

TILL	OUTWASH	SATURATED	BEDROCK	EIA
TFF: till, forest, flat	OF: outwash, forest, all slopes	SF: saturated, forest, all slopes	BFF: bedrock, forest, flat	ELDR: EIA Low Density Residential
TFL: till, forest, low	OP: outwash, pasture, all slopes	SP: saturated, pasture, all slopes	BFL: bedrock, forest, low	EHDR: EIA High Density Residential
TFM: till, forest, medium	OC: outwash, cropland, all slopes	SC: saturated, cropland, all slopes	BFM: bedrock, forest, medium	ECI: EIA Commercial / Industrial
TFS: till, forest, steep	OFR: outwash, forest residential, all slopes	SFR: saturated, forest residential, all slopes	BFS: bedrock, forest, steep	ER: EIA Road
TPF: till, pasture, flat	OLDR: outwash, low density residential, all slopes	SLDR: saturated, low density residential, all slopes	BPF: bedrock, pasture, flat	
TPL: till, pasture, low	OHDR: outwash, high density residential, all slopes	SHDR: saturated, high density residential, all slopes	BPL: bedrock, pasture, low	
TPM: till, pasture, medium	OCI: outwash, commercial/ industrial, all slopes	SCI: saturated, commercial/ industrial, all slopes	BPM: bedrock, pasture, medium	
TPS: till, pasture, steep	OR: outwash, major road, all slopes	SR: saturated, major road, all slopes	BPS: bedrock, pasture, steep	
TCF: till, cropland, flat			BCF: bedrock, cropland, flat	
TCL: till, cropland, low			BCL: bedrock, cropland, low	
TCM: till, cropland, medium			BCM: bedrock, cropland, medium	
TCS: till, cropland, steep			BCS: bedrock, cropland, steep	
TFRF: till, forest residential, flat			BFRF: bedrock, forest residential, flat	
TFRL: till, forest residential, low			BFRL: bedrock, forest residential, low	
TFRM: till, forest residential, medium			BFRM: bedrock, forest residential, medium	
TFRS: till, forest residential, steep			BFRS: bedrock, forest residential, steep	
TLDF: till, low density residential, flat			BLDF: bedrock, low density residential, flat	
TLDL: till, low density residential, low			BLDL: bedrock, low density residential, low	
TLDM: till, low density residential, medium			BLDM: bedrock, low density residential, medium	
TLDS: till, low density residential, steep			BLDS: bedrock, low density residential, steep	
THDF: till, high density residential, flat			BHDF: bedrock, high density residential, flat	
THDL: till, high density residential, low			BHDL: bedrock, high density residential, low	
THDM: till, high density residential, medium			BHDM: bedrock, high density residential, medium	

TILL	OUTWASH	SATURATED	BEDROCK	EIA
THDS: till, high density residential, steep			BHDS: bedrock, high density residential, steep	
TCIF: till, commercial/ industrial, flat			BCIF: bedrock, commercial/ industrial, flat	
TCIL: till, commercial/ industrial, low			BCIL: bedrock, commercial/ industrial, low	
TCIM: till, commercial/ industrial, medium			BCIM: bedrock, commercial/ industrial, medium	
TCIS: till, commercial/ industrial, steep			BCIS: bedrock, commercial/ industrial, steep	

Note that there are no cropland or bedrock categories in the Swamp Creek watershed.

5.2.4.3.3 Catchment Characterization

The location, areas, and slopes of PERLND and IMPLND categories within each catchment were determined using the methods previously discussed. Additional attributes (e.g., average elevation) were also calculated within the GIS.

5.2.4.3.3.1 Physical Parameters

The Swamp Creek watershed PERLND soil type and land use areas and IMPLND land use areas used in the HSPF model are summarized in Table 5.2-16. They are based on the GIS coverage and the delineation methodology described in Section 5.2.4.3.2.

Table 5.2-16 Swamp Creek Watershed PERLND/IMPLND Areas

Land Use	Till (acres)	Outwash (acres)	Saturated (acres)	EIA (acres)	Total (acres)
Forest	2190	541	296	0	3027
Pasture/Ag	451	39	0	0	490
Forest Residential	1357	130	85	0	1572
Low Density Residential	2896	924	115	246	4180
High Density Residential	3168	537	69	1743	5518
Commercial/Industrial	179	0	0	343	522
Roads	0	0	0	366	366
Total	**10241**	**2172**	566	**2697**	**15676**

Table 5.2-16 Swamp Creek Watershed PERLND/IMPLND Areas (cont'd)

Land Use	Till (%)	Outwash (%)	Saturated (%)	EIA (%)	Total (%)
Forest	14%	3%	2%	0%	19%
Pasture/Ag	3%	0%	0%	0%	3%
Forest Residential	9%	1%	1%	0%	10%
Low Density Residential	18%	6%	1%	2%	27%
High Density Residential	20%	3%	<1%	11%	35%
Commercial/Industrial	1%	0%	0%	2%	3%
Roads	0%	0%	0%	2%	2%
Total	**65%**	**14%**	**4%**	**17%**	**100%**

5.2.4.3.3.2 Additional Physical Data Needs for Water Quality Simulation

For Swamp Creek, shading was roughly estimated by inspection of aerial photographs and from data contained in the report: *Habitat Inventory and Assessment of Three Sammamish River Tributaries: North, Swamp, and Little Bear Creeks* (Fevold, et al., 2001). Since water temperature processes are a function of air temperature and air pressure, stream elevations and the elevation of the air temperature gage are also needed. Stream elevations were determined from the DEM. Also, water temperatures in the Swamp Creek model are affected by energy transfers between the water and the stream bed. Therefore, ground temperatures were estimated from groundwater temperatures in the King County area.

Little data are available to characterize Swamp Creek erosion and bed sediments. Bed widths were estimated from the channel bottom width data developed for the FTABLES, and they were confirmed with data from Fevold et al. (2001).

5.2.4.3.3.3 Calibration Parameter Values

Calibration parameter values were initially based on past applications (i.e., regional HSPF parameter set and the North Creek calibration) and the physical attributes found within the watershed. Some of these values were then modified to better represent the hydrologic processes observed in the Swamp Creek watershed. The final values were selected through the calibration process and a comparison of the simulated and recorded streamflow. Table 5.2-17 through Table 5.2-24 present the final PERLND and IMPLND parameter values selected for the Swamp Creek watershed.

Table 5.2-17 Final PERLND/IMPLND Parameter Values Lower Watershed (Part 1)

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
11	Till Forest Flat	4.0	0.080	350	0.027	0.45	0.998

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
12	Till Forest Low	3.5	0.070	300	0.073	0.45	0.998
13	Till Forest Med	3.0	0.060	250	0.117	0.45	0.998
14	Till Forest Steep	2.5	0.050	200	0.207	0.45	0.998
21	Till Pasture Flat	4.0	0.070	350	0.029	0.45	0.997
22	Till Pasture Low	3.5	0.060	300	0.071	0.45	0.997
23	Till Pasture Med	3.0	0.050	250	0.112	0.45	0.997
24	Till Past Steep	2.5	0.040	200	0.176	0.45	0.997
31	Till Forest Residential Flat	4.0	0.080	350	0.027	0.45	0.998
32	Till Forest Residential Low	3.5	0.070	300	0.073	0.45	0.998
33	Till Forest Residential Med	3.0	0.060	250	0.117	0.45	0.998
34	Till Forest Res Steep	2.5	0.050	200	0.207	0.45	0.998
41	Till Low Density Residential Flat	4.0	0.040	350	0.028	0.45	0.996
42	Till Low Density Residential Low	3.5	0.030	300	0.070	0.45	0.996
43	Till Low Density Residential Med	3.0	0.025	250	0.115	0.45	0.996
44	Till Low Density Res Steep	2.5	0.020	200	0.180	0.45	0.996
51	Till High Density Residential Flat	4.0	0.040	350	0.026	0.45	0.996
52	Till High Density Residential Low	3.5	0.030	300	0.068	0.45	0.996
53	Till High Density Residential Med	3.0	0.025	250	0.111	0.45	0.996
54	Till High Density Res Steep	2.5	0.020	200	0.170	0.45	0.996
61	Till Commercial/ Industrial Flat	4.0	0.040	350	0.025	0.45	0.996
62	Till Commercial/ Industrial Low	3.5	0.030	300	0.068	0.45	0.996
63	Till Commercial/ Industrial Med	3.0	0.025	250	0.109	0.45	0.996
64	Till Commercial/ Industrial Steep	2.5	0.020	200	0.166	0.45	0.996
71	Outwash Forest	5.0	2.000	300	0.106	0.30	0.996
72	Outwash Pasture	5.0	1.400	300	0.071	0.30	0.996
73	Outwash Forest Residential	5.0	2.000	300	0.106	0.30	0.996
74	Outwash Low	5.0	0.800	300	0.078	0.30	0.996

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
	Density Res						
75	Outwash High Density Res	5.0	0.800	300	0.061	0.30	0.996
76	Outwash Commercial/Ind	5.0	0.800	300	0.055	0.30	0.996
81	Saturated Forest	4.0	2.000	150	0.031	0.50	0.998
82	Saturated Pasture	4.0	1.800	150	0.021	0.50	0.998
83	Saturated Forest Residential	4.0	2.000	150	0.031	0.50	0.998
84	Saturated Low Density Res	4.0	1.000	150	0.026	0.50	0.998
85	Saturated High Density Res	4.0	1.000	150	0.027	0.50	0.998
86	Saturated Commercial/Ind	4.0	1.000	150	0.032	0.50	0.998

Table 5.2-18 Final PERLND/IMPLND Parameter Values Upper Watershed (Part 1)

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
211	Till Forest Flat	4.0	0.080	350	0.027	0.45	0.998
212	Till Forest Low	3.5	0.070	300	0.073	0.45	0.998
213	Till Forest Med	3.0	0.060	250	0.117	0.45	0.998
214	Till Forest Steep	2.5	0.050	200	0.207	0.45	0.998
221	Till Pasture Flat	4.0	0.070	350	0.029	0.45	0.997
222	Till Pasture Low	3.5	0.060	300	0.071	0.45	0.997
223	Till Pasture Med	3.0	0.050	250	0.112	0.45	0.997
224	Till Past Steep	2.5	0.040	200	0.176	0.45	0.997
231	Till Forest Residential Flat	4.0	0.080	350	0.027	0.45	0.998
232	Till Forest Residential Low	3.5	0.070	300	0.073	0.45	0.998
233	Till Forest Residential Med	3.0	0.060	250	0.117	0.45	0.998
234	Till Forest Res Steep	2.5	0.050	200	0.207	0.45	0.998
241	Till Low Density Residential Flat	4.0	0.040	350	0.028	0.45	0.996
242	Till Low Density Residential Low	3.5	0.030	300	0.070	0.45	0.996
243	Till Low Density Residential Med	3.0	0.025	250	0.115	0.45	0.996
244	Till Low Density Res Steep	2.5	0.020	200	0.180	0.45	0.996

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
251	Till High Density Residential Flat	4.0	0.040	350	0.026	0.45	0.996
252	Till High Density Residential Low	3.5	0.030	300	0.068	0.45	0.996
253	Till High Density Residential Med	3.0	0.025	250	0.111	0.45	0.996
254	Till High Density Res Steep	2.5	0.020	200	0.170	0.45	0.996
261	Till Commercial/ Industrial Flat	4.0	0.040	350	0.025	0.45	0.996
262	Till Commercial/ Industrial Low	3.5	0.030	300	0.068	0.45	0.996
263	Till Commercial/ Industrial Med	3.0	0.025	250	0.109	0.45	0.996
264	Till Commercial/ Industrial Steep	2.5	0.020	200	0.166	0.45	0.996
271	Outwash Forest	5.0	2.000	300	0.106	0.30	0.996
272	Outwash Pasture	5.0	1.400	300	0.071	0.30	0.996
273	Outwash Forest Residential	5.0	2.000	300	0.106	0.30	0.996
274	Outwash Low Density Res	5.0	0.800	300	0.078	0.30	0.996
275	Outwash High Density Res	5.0	0.800	300	0.062	0.30	0.996
276	Outwash Commercial/Ind	5.0	0.800	300	0.055	0.30	0.996
281	Saturated Forest	4.0	2.000	150	0.031	0.50	0.998
282	Saturated Pasture	4.0	1.800	150	0.021	0.50	0.998
283	Saturated Forest Residential	4.0	2.000	150	0.031	0.50	0.998
284	Saturated Low Density Res	4.0	1.000	150	0.026	0.50	0.998
285	Saturated High Density Res	4.0	1.000	150	0.027	0.50	0.998
286	Saturated Commercial/Ind	4.0	1.000	150	0.032	0.50	0.998

LZSN: Lower Zone Storage Nominal (inches)
INFILT: Infiltration (inches per hour)
LSUR: Length of surface flow path (feet)
SLSUR: Slope of surface flow path (feet/feet)
KVARY: Variable groundwater recession
AGWRC: Active Groundwater Recession Constant (per day)

Table 5.2-19 Final PERLND/IMPLND Parameter Values Lower Watershed (Part 2)

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
11	Till Forest Flat	2.0	2.0	0.00	0.01	0.0
12	Till Forest Low	2.0	2.0	0.00	0.01	0.0
13	Till Forest Med	2.0	2.0	0.00	0.01	0.0
14	Till Forest Steep	2.0	2.0	0.00	0.01	0.0
21	Till Pasture Flat	2.0	2.0	0.00	0.01	0.0
22	Till Pasture Low	2.0	2.0	0.00	0.01	0.0
23	Till Pasture Med	2.0	2.0	0.00	0.01	0.0
24	Till Past Steep	2.0	2.0	0.00	0.01	0.0
31	Till Forest Residential Flat	2.0	2.0	0.00	0.01	0.0
32	Till Forest Residential Low	2.0	2.0	0.00	0.01	0.0
33	Till Forest Residential Med	2.0	2.0	0.00	0.01	0.0
34	Till Forest Res Steep	2.0	2.0	0.00	0.01	0.0
41	Till Low Density Residential Flat	2.0	2.0	0.00	0.01	0.0
42	Till Low Density Residential Low	2.0	2.0	0.00	0.01	0.0
43	Till Low Density Residential Med	2.0	2.0	0.00	0.01	0.0
44	Till Low Density Res Steep	2.0	2.0	0.00	0.01	0.0
51	Till High Density Residential Flat	2.0	2.0	0.00	0.01	0.0
52	Till High Density Residential Low	2.0	2.0	0.00	0.01	0.0
53	Till High Density Residential Med	2.0	2.0	0.00	0.01	0.0
54	Till High Density Res Steep	2.0	2.0	0.00	0.01	0.0
61	Till Commercial/ Industrial Flat	2.0	2.0	0.00	0.01	0.0
62	Till Commercial/ Industrial Low	2.0	2.0	0.00	0.01	0.0
63	Till Commercial/ Industrial Med	2.0	2.0	0.00	0.01	0.0
64	Till Commercial/ Industrial Steep	2.0	2.0	0.00	0.01	0.0
71	Outwash Forest	2.0	2.0	0.00	0.01	0.0
72	Outwash Pasture	2.0	2.0	0.00	0.01	0.0

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
73	Outwash Forest Residential	2.0	2.0	0.00	0.01	0.0
74	Outwash Low Density Res	2.0	2.0	0.00	0.01	0.0
75	Outwash High Density Res	2.0	2.0	0.00	0.01	0.0
76	Outwash Commercial/Ind	2.0	2.0	0.00	0.01	0.0
81	Saturated Forest	10.0	2.0	0.00	0.02	0.7
82	Saturated Pasture	10.0	2.0	0.00	0.02	0.7
83	Saturated Forest Residential	10.0	2.0	0.00	0.02	0.7
84	Saturated Low Density Res	10.0	2.0	0.00	0.02	0.7
85	Saturated High Density Res	10.0	2.0	0.00	0.02	0.7
86	Saturated Commercial/Ind	10.0	2.0	0.00	0.02	0.7

Table 5.2-20 Final PERLND/IMPLND Parameter Values Upper Watershed (Part 2)

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
211	Till Forest Flat	2.0	2.0	0.85	0.02	0.0
212	Till Forest Low	2.0	2.0	0.85	0.02	0.0
213	Till Forest Med	2.0	2.0	0.85	0.02	0.0
214	Till Forest Steep	2.0	2.0	0.85	0.02	0.0
221	Till Pasture Flat	2.0	2.0	0.85	0.02	0.0
222	Till Pasture Low	2.0	2.0	0.85	0.02	0.0
223	Till Pasture Med	2.0	2.0	0.85	0.02	0.0
224	Till Past Steep	2.0	2.0	0.85	0.02	0.0
231	Till Forest Residential Flat	2.0	2.0	0.85	0.02	0.0
232	Till Forest Residential Low	2.0	2.0	0.85	0.02	0.0
233	Till Forest Residential Med	2.0	2.0	0.85	0.02	0.0
234	Till Forest Res Steep	2.0	2.0	0.85	0.02	0.0
241	Till Low Density Residential Flat	2.0	2.0	0.85	0.02	0.0
242	Till Low Density Residential Low	2.0	2.0	0.85	0.02	0.0

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
243	Till Low Density Residential Med	2.0	2.0	0.85	0.02	0.0
244	Till Low Density Res Steep	2.0	2.0	0.85	0.02	0.0
251	Till High Density Residential Flat	2.0	2.0	0.85	0.02	0.0
252	Till High Density Residential Low	2.0	2.0	0.85	0.02	0.0
253	Till High Density Residential Med	2.0	2.0	0.85	0.02	0.0
254	Till High Density Res Steep	2.0	2.0	0.85	0.02	0.0
261	Till Commercial/ Industrial Flat	2.0	2.0	0.85	0.02	0.0
262	Till Commercial/ Industrial Low	2.0	2.0	0.85	0.02	0.0
263	Till Commercial/ Industrial Med	2.0	2.0	0.85	0.02	0.0
264	Till Commercial/ Industrial Steep	2.0	2.0	0.85	0.02	0.0
271	Outwash Forest	2.0	2.0	0.20	0.02	0.0
272	Outwash Pasture	2.0	2.0	0.20	0.02	0.0
273	Outwash Forest Residential	2.0	2.0	0.20	0.02	0.0
274	Outwash Low Density Res	2.0	2.0	0.20	0.02	0.0
275	Outwash High Density Res	2.0	2.0	0.20	0.02	0.0
276	Outwash Commercial/Ind	2.0	2.0	0.20	0.02	0.0
281	Saturated Forest	10.0	2.0	0.00	0.03	0.7
282	Saturated Pasture	10.0	2.0	0.00	0.03	0.7
283	Saturated Forest Residential	10.0	2.0	0.00	0.03	0.7
284	Saturated Low Density Res	10.0	2.0	0.00	0.03	0.7
285	Saturated High Density Res	10.0	2.0	0.00	0.03	0.7
286	Saturated Commercial/Ind	10.0	2.0	0.00	0.03	0.7

INFEXP: Infiltration Exponent
INFILD: Infiltration ratio (maximum to mean)
DEEPFR: Fraction of groundwater to deep aquifer or inactive storage
BASETP: Base flow (from groundwater) Evapotranspiration fraction

AGWETP: Active Groundwater Evapotranspiration fraction

Table 5.2-21 Final PERLND/IMPLND Parameter Values Lower Watershed (Part 3)

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
11	Till Forest Flat	0.20	1.00	0.35	1.0	0.50	Monthly
12	Till Forest Low	0.20	0.70	0.35	0.9	0.40	Monthly
13	Till Forest Med	0.20	0.50	0.35	0.8	0.30	Monthly
14	Till Forest Steep	0.20	0.30	0.35	0.7	0.20	Monthly
21	Till Pasture Flat	0.15	0.70	0.30	0.9	0.50	Monthly
22	Till Pasture Low	0.15	0.50	0.30	0.8	0.40	Monthly
23	Till Pasture Med	0.15	0.30	0.30	0.7	0.30	Monthly
24	Till Past Steep	0.15	0.20	0.30	0.6	0.20	Monthly
31	Till Forest Residential Flat	0.20	1.00	0.35	1.0	0.50	Monthly
32	Till Forest Residential Low	0.20	0.70	0.35	0.9	0.40	Monthly
33	Till Forest Residential Med	0.20	0.50	0.35	0.8	0.30	Monthly
34	Till Forest Res Steep	0.20	0.30	0.35	0.7	0.20	Monthly
41	Till Low Density Residential Flat	0.10	0.50	0.25	0.8	0.40	Monthly
42	Till Low Density Residential Low	0.10	0.30	0.25	0.7	0.30	Monthly
43	Till Low Density Residential Med	0.10	0.20	0.25	0.6	0.25	Monthly
44	Till Low Density Res Steep	0.10	0.10	0.25	0.5	0.20	Monthly
51	Till High Density Residential Flat	0.10	0.50	0.25	0.8	0.40	Monthly
52	Till High Density Residential Low	0.10	0.30	0.25	0.7	0.30	Monthly
53	Till High Density Residential Med	0.10	0.20	0.25	0.6	0.25	Monthly
54	Till High Density Res Steep	0.10	0.10	0.25	0.5	0.20	Monthly
61	Till Commercial/ Industrial Flat	0.10	0.50	0.25	0.8	0.40	Monthly
62	Till Commercial/ Industrial Low	0.10	0.30	0.25	0.7	0.30	Monthly
63	Till Commercial/ Industrial Med	0.10	0.20	0.25	0.6	0.25	Monthly
64	Till Commercial/ Industrial Steep	0.10	0.10	0.25	0.5	0.20	Monthly
71	Outwash Forest	0.20	0.50	0.35	0.0	0.70	Monthly
72	Outwash Pasture	0.15	0.50	0.30	0.0	0.70	Monthly
73	Outwash Forest	0.20	0.50	0.35	0.0	0.70	Monthly

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
	Residential						
74	Outwash Low Density Res	0.10	0.50	0.25	0.0	0.70	Monthly
75	Outwash High Density Res	0.10	0.50	0.25	0.0	0.70	Monthly
76	Outwash Commercial/Ind	0.10	0.50	0.25	0.0	0.70	Monthly
81	Saturated Forest	0.20	3.00	0.50	1.0	0.50	Monthly
82	Saturated Pasture	0.15	3.00	0.50	1.0	0.50	Monthly
83	Saturated Forest Residential	0.20	3.00	0.50	1.0	0.50	Monthly
84	Saturated Low Density Res	0.10	3.00	0.50	1.0	0.50	Monthly
85	Saturated High Density Res	0.10	3.00	0.50	1.0	0.50	Monthly
86	Saturated Commercial/Ind	0.10	3.00	0.50	1.0	0.50	Monthly

Table 5.2-22 Final PERLND/IMPLND Parameter Values Upper Watershed (Part 3)

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
211	Till Forest Flat	0.20	1.00	0.35	1.0	0.50	Monthly
212	Till Forest Low	0.20	0.70	0.35	0.9	0.40	Monthly
213	Till Forest Med	0.20	0.50	0.35	0.8	0.30	Monthly
214	Till Forest Steep	0.20	0.30	0.35	0.7	0.20	Monthly
221	Till Pasture Flat	0.15	0.70	0.30	0.9	0.50	Monthly
222	Till Pasture Low	0.15	0.50	0.30	0.8	0.40	Monthly
223	Till Pasture Med	0.15	0.30	0.30	0.7	0.30	Monthly
224	Till Past Steep	0.15	0.20	0.30	0.6	0.20	Monthly
231	Till Forest Residential Flat	0.20	1.00	0.35	1.0	0.50	Monthly
232	Till Forest Residential Low	0.20	0.70	0.35	0.9	0.40	Monthly
233	Till Forest Residential Med	0.20	0.50	0.35	0.7	0.30	Monthly
234	Till Forest Res Steep	0.20	0.30	0.35	0.6	0.20	Monthly
241	Till Low Density Residential Flat	0.10	0.50	0.25	0.8	0.40	Monthly
242	Till Low Density Residential Low	0.10	0.30	0.25	0.7	0.30	Monthly
243	Till Low Density Residential Med	0.10	0.20	0.25	0.6	0.25	Monthly
244	Till Low Density Res Steep	0.10	0.10	0.25	0.5	0.20	Monthly
251	Till High Density Residential Flat	0.10	0.50	0.25	0.8	0.40	Monthly
252	Till High Density Residential Low	0.10	0.30	0.25	0.7	0.30	Monthly
253	Till High Density Residential Med	0.10	0.20	0.25	0.6	0.25	Monthly
254	Till High Density Res Steep	0.10	0.10	0.25	0.5	0.20	Monthly
261	Till Commercial/ Industrial Flat	0.10	0.50	0.25	0.8	0.40	Monthly
262	Till Commercial/ Industrial Low	0.10	0.30	0.25	0.7	0.30	Monthly
263	Till Commercial/ Industrial Med	0.10	0.20	0.25	0.6	0.25	Monthly
264	Till Commercial/ Industrial Steep	0.10	0.10	0.25	0.5	0.20	Monthly
271	Outwash Forest	0.20	0.50	0.35	0.0	0.70	Monthly
272	Outwash Pasture	0.15	0.50	0.30	0.0	0.70	Monthly
273	Outwash Forest	0.20	0.50	0.35	0.0	0.70	Monthly

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
	Residential						
274	Outwash Low Density Res	0.10	0.50	0.25	0.0	0.70	Monthly
275	Outwash High Density Res	0.10	0.50	0.25	0.0	0.70	Monthly
276	Outwash Commercial/Ind	0.10	0.50	0.25	0.0	0.70	Monthly
281	Saturated Forest	0.20	3.00	0.50	1.0	0.50	Monthly
282	Saturated Pasture	0.15	3.00	0.50	1.0	0.50	Monthly
283	Saturated Forest Residential	0.20	3.00	0.50	1.0	0.50	Monthly
284	Saturated Low Density Res	0.10	3.00	0.50	1.0	0.50	Monthly
285	Saturated High Density Res	0.10	3.00	0.50	1.0	0.50	Monthly
286	Saturated Commercial/Ind	0.10	3.00	0.50	1.0	0.50	Monthly

CEPSC: Interception storage (inches)
UZSN: Upper Zone Storage Nominal (inches)
NSUR: Surface roughness (Manning's n)
INTFW: Interflow index
IRC: Interflow Recession Constant (per day)
LZETP: Lower Zone Evapotranspiration fraction (see Table 5.2-23 for monthly values)

Table 5.2-23 Final PERLND/IMPLND Parameter Values Lower and Upper Watershed (Part 4): Monthly LZETP Values

No.	PERLND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11-14*	Till Forest	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
21-24*	Till Pasture	0.20	0.20	0.20	0.25	0.30	0.35	0.40	0.40	0.40	0.35	0.30	0.20
31-34*	Till Forest Residential	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
41-44*	Till Low Density Residential	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
51-54*	Till High Density Residential	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
61-64*	Till Commercial/ Industrial	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
71*	Outwash Forest	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
72*	Outwash Pasture	0.20	0.20	0.20	0.25	0.30	0.35	0.40	0.40	0.40	0.35	0.30	0.20
73*	Outwash Forest Residential	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
74*	Outwash Low Density Res	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
75*	Outwash High Density Res	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
76*	Outwash Commercial/Ind	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
81*	Saturated Forest	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
82*	Saturated Pasture	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
83*	Saturated Forest Residential	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
84*	Saturated Low Density Res	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
85*	Saturated High Density Res	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
86*	Saturated Commercial/Ind	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50

*Same values were used for the 200-series (upper watershed) PERLNDs.

Table 5.2-24 Final PERLND/IMPLND Parameter Values (Part 5)

No.	IMPLND	LSUR	SLSUR	NSUR	RETSC
91*	Low Density Residential	150	0.01	0.10	0.10
92*	High Density Residential	150	0.01	0.10	0.10
91*	Commercial/Industrial	150	0.01	0.10	0.10
92*	Road	150	0.01	0.10	0.10

*Same values were used for the 200-series (upper watershed) IMPLNDs.

LSUR: Length of surface flow path (feet) for impervious area
SLSUR: Slope of surface flow path (feet/feet) for impervious area
NSUR: Surface roughness (Manning's n) for impervious area
RETSC: Surface retention storage (inches) for impervious area

Additional information on the HSPF model parameters and algorithms can be found in the HSPF User's Manual for Release 12 (Bicknell, et al. 2002).

Parameter values are not included for bedrock categories because these PERLND categories are not found in the Swamp Creek watershed.

The only difference between the lower and upper watershed PERLNDs was in terms of the groundwater. The upper watershed loses most of its groundwater. This is represented by a deep fraction (DEEPFR) of 0.85 for till and 0.20 for outwash. In the lower watershed (downstream of the I-405 gage) the DEEPFR was set to zero for all PERLNDs. BASETP was also set higher (0.02) in the upper watershed than the lower (0.01) to represent the greater access of vegetation to the stream channel in the upper watershed compared to the lower.

5.2.4.3.4 CONVEYANCE SYSTEM SEGMENTATION AND CHARACTERIZATION

The current segmentation scheme is primarily the result of the catchment delineation. The modeling scheme incorporates a single HSPF reach per catchment.

5.2.4.3.4.1 HSPF Reach Network

The current network includes 26 reaches totaling approximately 15 miles in length; with the individual reaches ranging from approximately 0.4 to 2.1 miles in length. Within the channel module (RCHRES) of HSPF, each stream reach is represented by a hydraulic function table, called an FTABLE, which defines the flow rate, surface area, and volume as a function of the water depth in the channel reach. In order to develop an FTABLE, the channel's geometric and hydraulic properties (e.g., Manning's n) were first defined using observed data or estimated values.

Snohomish County has provided FTABLEs from the Snohomish County Drainage Needs Report study. AQUA TERRA staff reviewed and aggregated these FTABLEs, where needed, to match the model's reach lengths.

Table 5.2-178 shows the data used to construct the FTABLEs for North Creek.

Table 5.2-25 Stream Reach Data

RCHRES	RCHRES Length (mi)	Upstream Elev (ft)	Downstream Elev (ft)	Change in Elev (ft)	Slope (%)	DNR RCHRES
122	0.886	344	272	72	1.5%	670,675,680,685, 690,700
132	0.977	413	318	95	1.8%	650,655,660,665
142	1.016	420	380	39	0.7%	634
152	1.191	380	341	39	0.6%	630,632
162	0.507	341	341	0	0.0%	627
172	1.037	341	328	13	0.2%	620,624
182	0.972	328	292	36	0.7%	610,615
192	2.049	292	200	92	0.8%	600,605
272	0.485	459	456	3	0.1%	900
282	0.913	456	407	49	1.0%	852,860,872,876, 880
292	1.484	407	305	102	1.3%	800,804,808,816, 828,836,844
362	1.131	538	476	62	1.0%	500,505,520
372	1.690	558	436	121	1.4%	405,420,425,430, 435,440,445
382	**1.774**	**548**	**508**	**39**	**0.4%**	**565,570,575**
392	**0.680**	**508**	**476**	**33**	**0.9%**	**555**
402	**0.863**	**476**	**449**	**26**	**0.6%**	**485,495**
412	**0.356**	**449**	**449**	**0**	**0.0%**	**455**
422	**0.421**	**449**	**436**	**13**	**0.6%**	**450**
432	**1.670**	**436**	**361**	**75**	**0.9%**	**296,308,320,344, 359**
442	**1.188**	**361**	**321**	**40**	**0.6%**	**239,248,266,278, 287,293**
452	**1.059**	**321**	**298**	**23**	**0.4%**	**203,215,227**
462	**2.140**	**298**	**200**	**98**	**0.9%**	**125,140,145,170**
472	**1.345**	**200**	**134**	**66**	**0.9%**	**110,120**
482	**0.934**	**134**	**79**	**55**	**1.1%**	**65,75,90**
492	**1.122**	**79**	**33**	**46**	**0.8%**	**25,50**
502	**1.202**	**33**	**20**	**13**	**0.2%**	**5**

Note that the Swamp Creek mainsteam reaches (382 to 502) are shown in bold text.

5.3 MODEL CALIBRATION

The calibration of HSPF to the Swamp Creek watershed follows the standard model calibration procedures as described in the HSPF Application Guide (Donigian et al., 1984), in numerous watershed studies over the past 20 years (see HSPF Bibliography [Donigian, 2002a]), and as recently summarized by Donigian (2002b). This model calibration presentation focuses solely on the hydrologic parameters; water quality calibration will follow and the calibration report will be updated with the water quality calibration discussion when it is completed.

5.3.1 WATER QUANTITY

5.3.1.1 OVERVIEW OF HSPF CALIBRATION AND VALIDATION PROCEDURES

For HSPF, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. This approach is required for parameters that cannot be deterministically, and uniquely, evaluated from topographic, climatic, edaphic, or physical/chemical characteristics of the watershed and compounds of interest. Fortunately, the large majority of HSPF parameters do not fall in this category. Calibration is based on several years of simulation to evaluate parameters under a variety of climatic, soil moisture, and water quality conditions. Calibration results in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period. Any biases in the calibration data may affect the quality of the calibration and will be noted.

Calibration includes the comparison of both monthly and annual values, and individual storm events, whenever sufficient data are available for these comparisons. All of these comparisons are performed for a proper calibration of hydrology parameters. In addition, when a continuous observed record is available, such as for streamflow, simulated and observed values are analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

A weight of evidence approach, as described above, is most widely used and accepted when models are examined and judged for acceptance as no single procedure or statistic is widely accepted as measuring, nor capable of establishing, acceptable model performance. Therefore, the calibration relied on numerous statistical tests (e.g., correlation tests, Model Fit Efficiency) and graphical plots (e.g., scatter, time series, frequency) to determine the model's ability to mimic the system.

Calibration is a hierarchical process beginning within hydrology calibration of both runoff and streamflow, followed by sediment erosion and sediment transport calibration, and finally calibration of water quality constituents, including water temperature. This calibration report addresses only the hydrology calibration.

When modeling land surface processes, hydrologic calibration must precede sediment and water quality calibration since runoff is the transport mechanism by which nonpoint pollution occurs. Likewise, adjustments to the instream hydraulics simulation must be completed before instream sediment and water quality transport and processes are calibrated. Each of these steps is discussed below with the emphasis on the key calibration parameters.

5.3.1.2 HYDROLOGIC CALIBRATION AND KEY CALIBRATION PARAMETERS

Hydrologic simulation combines the physical characteristics of the watershed and the observed meteorologic data series to produce the simulated hydrologic response. All watersheds have similar hydrologic components, but they are generally present in different combinations; thus different hydrologic responses occur on individual watersheds. HSPF simulates runoff from four components: surface runoff from impervious areas directly connected to the channel network, surface runoff from pervious areas, interflow from pervious areas, and groundwater flow. Because the historic streamflow is not divided into these four units, the relative relationship among these components must be inferred from the examination of many events over several years of continuous simulation.

A complete hydrologic calibration involves a successive examination of the following four characteristics of the watershed hydrology, in the order shown: (1) annual water balance, (2) seasonal and monthly flow volumes, (3) baseflow, and (4) storm events. Simulated and observed values for reach characteristic are examined and critical parameters are adjusted to attain acceptable levels of agreement (discussed further below).

The annual water balance specifies the ultimate destination of incoming precipitation and is indicated as:

$$\textbf{Runoff} = \textbf{Precipitation} - \textbf{Actual Evapotranspiration} - \textbf{Deep Percolation}$$

$$- \Delta\textbf{Soil Moisture}$$

HSPF requires input precipitation and potential evapotranspiration (PET), which effectively drive the hydrology of the watershed; actual evapotranspiration (calculated by the model from the input potential); and ambient soil moisture conditions. Thus, both precipitation and evaporation inputs must be accurate and representative of the watershed conditions. It is often necessary to adjust the input data derived from neighboring stations that may be some distance away in order to reflect conditions on the watershed. HSPF allows the use of factors (referred to as MFACT) that uniformly adjust the input data to watershed conditions, based on local isohyetal and evaporation patterns. In addition to the input meteorologic data series, the critical parameters that govern the annual water balance are as follows:

LZSN - lower zone soil moisture storage (inches).

LZETP - vegetation evapotranspiration index (dimensionless).

INFILT - infiltration index for division of surface and subsurface flow (inches/hour).

UZSN - upper zone soil moisture storage (inches).

DEEPFR - fraction of groundwater inflow to deep recharge (dimensionless).

Thus, from the water balance equation, if precipitation is measured on the watershed, and if deep percolation to groundwater is small or negligible, actual evapotranspiration must be adjusted to cause a change in the long-term runoff component of the water balance. Changes in LZSN and LZETP affect the actual evapotranspiration by making more or less moisture available to evaporate or transpire. Both LZSN and INFILT also have a major impact on percolation and are important in obtaining an annual water balance. In addition, on extremely small watersheds (less than 200 to 500 acres) that contribute runoff only during and immediately following storm events, the UZSN parameter can also affect annual runoff volumes because of its impact an individual storm events (described below). Whenever there are losses to deep groundwater, such as recharge, or subsurface flow not measured at the flow gage, DEEPFR is used to represent this loss from the annual water balance.

For the Swamp watershed LZSN values were decreased for till soils (the predominate soil type in the watershed) from 4.5 to a range from 4.0 to 2.5 inches, dependent on slope (steeper slopes, lower LZSN values – see Table 5.2-17). Outwash and saturated LZSN values were set to regional values of 5.0 and 4.0 inches, respectively. LZETP values were adjusted monthly using the MON-LZETPARM Block in HSPF. LZETP monthly values varied by PERLND vegetation types (with forest values higher than pasture values, which in turn, are higher than residential landscaping values) and by season (winter low; summer high – see Table 5.2-23). For forest PERLNDs the monthly LZETP values are relatively constant and varied from 0.60 in January to 0.70 in August; pasture monthly values varied from 0.20 to 0.40. UZSN values were increased by 50 percent (Table 5.2-21) from the regional values. DEEPFR was changed from its initial value of zero to 0.85 for till soils and 0.20 for outwash soils in the upper watershed and 0.00 for both in the lower (Table 5.2-19), as previously discussed. DEEPFR represents the fraction of groundwater that bypasses the stream gage and recharges the underlying aquifer or flows directly to the Sammamish River.

In the next step in hydrologic calibration, after an annual water balance was obtained, the seasonal or monthly distribution of runoff was adjusted with use of INFILT, the infiltration parameter defined above. This seasonal distribution was accomplished by INFILT by dividing the incoming moisture among surface runoff, interflow, upper zone soil moisture storage, and percolation to lower zone soil moisture and groundwater storage. Increasing INFILT reduced immediate surface runoff (including interflow) and increased the groundwater component; decreasing INFILT produced the opposite result.

The USGS regional values for till PERLNDs were used as a starting point and then varied by slope and land use. The forest INFILT value varied from 0.08 to 0.50 (steeper slope, lower INFILT – see Table 5.2-17). The pasture INFILT ranged from 0.07 to 0.04. The urban landscaping INFILT varied from 0.04 to 0.02 for the Swamp Creek watershed.

The focus of the next stage in calibration was the baseflow component. This portion of the flow was adjusted in conjunction with the seasonal/monthly flow calibration (previous step) because moving runoff volume between seasons often means transferring the surface runoff from storm events in wet seasons to low-flow periods during dry seasons. By increasing INFILT, runoff was delayed and occurred later in the year as an increased groundwater or baseflow. The shape of the groundwater recession; i.e., the change in baseflow discharge, is controlled by the following parameters:

AGWRC - groundwater recession rate (per day).

KVARY - index for nonlinear groundwater recession.

AGWRC is calculated as the rate of baseflow (i.e., groundwater discharge to the stream) on one day divided by the baseflow on the previous day; thus AGWRC is the parameter that controls the rate of outflow from the groundwater storage. Using hydrograph separation techniques, values of AGWRC are often calculated as the slope of the receding baseflow portion of the hydrograph; these initial values are then adjusted as needed through calibration. The KVARY index allows users to impose a nonlinear recession that so that the slope can be adjusted as a function of the groundwater gradient. KVARY is usually set to zero unless the observed flow record shows a definite change in the recession rate (i.e., slope) as a function of wet and dry seasons.

For the Swamp watershed the AGWRC value was set to the USGS regional value of 0.996 for all soils (Table 5.2-17). KVARY was found to differ slightly from the regional value of 0.50 for till and was set to 0.45. KVARY for outwash and saturated did not change from their regional values of 0.30 and 0.50, respectively.

In the final stage of hydrologic calibration, after an acceptable agreement was attained for annual/monthly volumes and baseflow conditions, simulated hydrographs for selected storm events were effectively altered with UZSN and the following parameters:

INTFW - Interflow inflow parameter (dimensionless).

IRC - Interflow recession rate (per day).

Both INTFW and IRC were used to adjust the shape of the hydrograph to better agree with observed values; both parameters are evaluated primarily from past experience and modeling studies, and then adjusted in calibration. Also, minor adjustments to the INFILT parameter were used to improve simulated hydrographs; however, adjustments to INFILT were minimal to prevent disruption of the established annual and monthly water balance. Examination of both daily and short-time interval (e.g., hourly) flows were made.

INTFW was varied from 1.00 to 0.70 for till forest (see Table 5.2-21). Lower values were used for steeper slopes to increase surface runoff and decrease interflow. For till pasture the values ranged from 0.90 to 0.60; till landscaping had values between 0.80 and 0.50. The reason for the low till INTFW values was because in the water quality calibration it was found that there was insufficient surface runoff to provide the measured loadings. Decreasing the till INTFW values produced more surface runoff (and less interflow) without significantly changing the hydrology calibration. Outwash INTFW values were set to the regional value of 0.0 (only surface runoff and groundwater are produced by outwash soils), as were saturated INTFW values (1.0).

IRC varied from 0.50 to 0.20 to produce relatively slow interflow runoff for forest and pasture on till soils, with lower values at higher slopes (Table 5.2-21). The till landscaping IRC values were lower (0.40 to 0.20). Outwash IRC values are set to 0.70 (regional values), but have no impact on the simulation because there is no outwash interflow, as noted above. Saturated IRC values were also set to regional values (0.50).

As part of the calibration process it was found that the upper watershed loses most of its groundwater, as the observed base flow at the Snohomish County gage near I-405 is only in the range of 1 cfs. This loss of groundwater is consistent with the USGS regional study by Dinicola (1989) and previous Swamp Creek modeling done for Snohomish County (RW Beck, 2002). The two downstream gages show larger base flows that are more typical of groundwater inflow to the stream.

5.3.1.3 COMPARISONS PERFORMED

The hydrologic calibration was performed for the time period of water year 1998 through water year 2002. The available flow data used the continuous flow records at the Snohomish County gage on Swamp Creek near I-405 and King County gage 56B. The Snohomish County streamflow recorded near 228th Street SE was too short to provide significant calibration statistics.

The following specific comparisons of simulated and observed values were performed:

- Annual and monthly runoff volumes (inches)
- Hourly and daily time series of flow (cfs)
- Flow duration values (cfs)

Annual runoff volumes at the Snohomish County gage near I-405 for water years 1998 through 2002 are shown in Table 5.3-1a. The average daily flows and annual volumes show that the simulated results match well with the observed values, only differing by 3.9 percent. The correlation coefficient is 0.94 and the model fit efficiency is 0.89. These values show a good calibration at this location.

Table 5.3-1a Flow Statistics at Snohomish County Gage near I-405 (Oct 1997 – Sep 2002)

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)
Mean	13.87	13.35	0.52	3.9%
Geometric Mean	5.51	5.63	-0.12	-2.1%
Correlation Coefficient	0.94			
Coefficient of Determination	0.89			
Mean Error	-0.521			
Mean Absolute Error	3.574			
RMS Error	7.57			
Nash Sutcliffe	0.11			
Model Fit Efficiency	0.89			
Skill Score	0.57			

Annual runoff volumes at King County gage 56B for the period of October 1999 through June 2001 are shown in Table 5.3-1b. The average daily flows and annual volumes show that the simulated results are not as good of a match compared to the Snohomish County gage results. Total volumes are low. The correlation coefficient is 0.93 and the model fit efficiency is 0.86. These values show a fair calibration at this location for this time period.

Table 5.3-2b Flow Statistics at King County Gage 56B (Oct 1999 – Jun 2001)

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)
Mean	29.56	32.92	-3.36	-10.2%
Geometric Mean	18.13	22.14	-4.01	-18.1%
Correlation Coefficient	0.93			
Coefficient of Determination	0.87			
Mean Error	3.354			
Mean Absolute Error	8.39			
RMS Error	13.8			
Nash Sutcliffe	0.14			
Model Fit Efficiency	0.86			
Skill Score	0.42			

A comparison of the annual volumes at the Snohomish County gage by water year in Table 5.3-3a shows some variability from water year to water year, with 2002 being low and 1999 being high, but in general a good match.

Table 5.3-3a Annual Volumes at Snohomish County Gage near I-405 (Oct 1997 – Sep 2002)

Water Year	Precip (in)	Sim (in)	Obs (in)	Difference (in)	Difference (%)
1998	41.83	19.93	18.49	1.44	7.8%
1999	54.86	26.87	23.71	3.16	13.3%
2000	42.56	18.25	16.84	1.41	8.4%
2001	31.83	9.24	8.65	0.59	6.8%
2002	45.98	22.24	25.23	-2.99	-11.9%
Average	43.41	19.31	18.58	0.72	3.9%

A comparison of the annual volumes at King County gage 56B by water year in Table 5.3-3b shows water year 2001 (actually October 2000 through June 2001) very low, although this period was high at the Snohomish County gage. Due to a very short record, this low year skews the average results at 56B.

Table 5.3-4b Annual Volumes at King County Gage 56B (Oct 1999 – Jun 2001)

Water Year	Precip (in)	Sim (in)	Obs (in)	Difference (in)	Difference (%)
2000	43.33	21.11	21.76	-0.65	-3.0%
2001	27.24	9.71	12.56	-2.85	-22.7%
Average	35.29	15.41	17.16	-1.75	-10.2%

Mean monthly volumes for the Snohomish County gage near I-405 are shown in **Error! Reference source not found.**a. The mean monthly simulated values are low compared to the observed values in the months of March through June and high in October and November. The flows in these transition months shows that the observed flow changes from dry to wet (October to November) and wet to dry (March to June) are delayed compared to the simulated data. This is a timing problem that does not affect the overall calibration volume accuracy.

Table 5.3-3a Mean Monthly Flow Statistics at Snohomish County Gage near I-405

Month	Sim (in)	Obs (in)	Diff (in)	Diff (%)
Jan	3.63	3.53	0.10	2.8%
Feb	2.96	2.82	0.14	5.0%
Mar	2.19	2.26	-0.07	-3.1%
Apr	1.05	1.19	-0.14	-12.0%
May	0.72	0.78	-0.06	-7.9%
Jun	0.55	0.58	-0.03	-4.7%
Jul	0.36	0.35	0.01	2.3%
Aug	0.19	0.16	0.02	13.5%
Sep	0.15	0.13	0.02	14.5%
Oct	1.27	0.78	0.49	61.9%
Nov	3.20	2.74	0.45	16.6%
Dec	3.06	3.26	-0.20	-6.2%
Total	19.31	18.58	0.72	3.9%

Mean monthly volumes for King County gage 56B are shown in **Error! Reference source not found.**b. The mean monthly simulated values are consistently low compared to the observed values, except for the months of September through November. This consistency is probably related to the problem of accurately modeling the groundwater contribution to the flow at this location and cannot be easily resolved. Also, the King County gage data is only for a 21-month period (compared to 48 months at the Snohomish County gage) and is heavily weighted by water year 2001, which was under simulated.

Table 5.3-3b Mean Monthly Flow Statistics at King County Gage 56B

Month	Sim (in)	Obs (in)	Diff (in)	Diff (%)
Jan	2.28	2.68	-0.40	-15.0%
Feb	1.76	2.08	-0.32	-15.5%
Mar	1.81	2.08	-0.27	-13.2%
Apr	1.10	1.41	-0.30	-21.5%
May	0.83	0.97	-0.14	-14.0%
Jun	0.82	0.90	-0.08	-8.5%
Jul	0.39	0.40	-0.01	-3.0%
Aug	0.29	0.39	-0.10	-24.9%
Sep	0.43	0.40	0.03	7.0%
Oct	0.94	0.80	0.14	16.9%
Nov	3.09	2.90	0.19	6.5%
Dec	2.23	2.75	-0.52	-18.9%
Total	15.96	17.75	-1.79	-10.1%

Error! Reference source not found.4a uses the HSPF Expert System statistics to evaluate the accuracy of the calibration. The simulated and observed flow values were divided into a number of categories and then evaluated according to defined criteria that allow the user to target specific flow ranges and events, such as the highest 10% of the flows, 50% low flows, summer storm volumes, etc. The criteria values range from 10 percent error to 20 percent error, depending on the type of flow range. Of the 12 criteria show Table 4.3-4a, eight are met with either excellent or good comparisons. Storm peaks are over simulated, although storm volumes are good. The storm peaks and volume calculations were based on a total of 29 winter storm events and 11 summer storms during the fiver-year calibration period.

The calibration tends to over estimate the peak flows, but under estimate summer storm volumes. The Expert System results, even with these differences, when viewed together with the other calibration information, as shown in both tables and figures, support the conclusion that the calibration is sufficiently accurate for the purposes of this study.

Table 5.3-4a Expert System Statistics at Snohomish Co Gage near I-405 (Oct 1997 – Sep 2002)

	Sim	Obs	Diff	Diff (%)	Criteria (%)	Meets Criteria
Total (in)	19.31	18.58	0.73	3.9%	10%	Good
10% high (in)	9.98	8.98	1.00	11.1%	10%	Poor
25% high (in)	15.01	13.66	1.35	9.9%	15%	Good
50% low (in)	1.35	1.52	-0.17	-11.2%	15%	Fair
25% low (in)	0.40	0.35	0.05	14.3%	15%	Fair
10% low (in)	0.11	0.11	0.00	0.0%	15%	Excellent
storm volume (in)	14.12	13.22	0.90	6.8%	20%	Good
Average storm peak (cfs)	119.44	91.95	27.49	29.9%	15%	Poor
summer volume (in)	1.25	1.22	0.03	2.5%	15%	Excellent
winter volume (in)	16.30	15.40	0.90	5.8%	10%	Good
summer storms (in)	0.52	0.51	0.01	2.0%	10%	Excellent
winter storms (in)	12.81	11.95	0.86	7.2%	15%	Good

Expert System statistics were also computed for King County Gage 56B (Table 4.3-4b). As expected, the results are not as good as those at the Snohomish County gage. Only four of the 12 criteria are met with excellent or good comparisons. High flows are over simulated while low flows are under simulated.

Table 5.3-4b Expert System Statistics at King Co Gage 56B (Oct 1999 – Jun 2001)

	Sim	Obs	Diff	Diff (%)	Criteria (%)	Meets Criteria
Total (in)	15.41	17.16	-1.75	-10.2%	10%	Poor
10% high (in)	6.68	6.24	0.44	7.1%	10%	Fair
25% high (in)	10.44	10.44	0.00	0.0%	15%	Excellent
50% low (in)	2.20	2.96	-0.76	-25.7%	15%	Poor
25% low (in)	0.82	0.98	-0.16	-16.3%	15%	Poor
10% low (in)	0.27	0.32	-0.05	-15.6%	15%	Poor
storm volume (in)	11.55	12.33	-0.78	-6.3%	20%	Good
Average storm peak (cfs)	235.78	146.47	89.31	61.0%	15%	Poor
summer volume (in)	2.09	1.95	0.14	7.2%	15%	Good
winter volume (in)	12.10	13.29	-1.19	-9.0%	10%	Fair
summer storms (in)	0.52	0.48	0.04	8.3%	10%	Fair
winter storms (in)	10.25	11.07	-0.82	-7.4%	15%	Good

Figure 4-3.1 shows the daily simulated and observed streamflow at the Snohomish County gage near I-405 for the period of October 1997 through September 2002. Figure 5.3-2 shows the flow duration for the same period and demonstrates a good match.

Figure 4.3-3 and Figure 5.3-4 compare the I-405 gage hourly simulated and observed streamflow values for the winter flow periods of December 1998 and December 1999, respectively.

Monthly simulated and observed flow volumes are shown in Figure 4-3.5. A scatter plot of the simulated and observed daily values are presented in Figure 5.3-6. The scatter plot shows a correlation coefficient of 0.94. Daily residual values are shown in Figure 4.3-7.

The same series of plots are provided for King County gage 56B in figures 4.3-8 through 4.3-14.

Because of the short period of record for the Snohomish County stream gage near 228th Street SE fewer plots of simulated and observed flows were produced at this location.

Figure 5.3-1 Snohomish Co Gage near I-405 Daily Flow Time Series

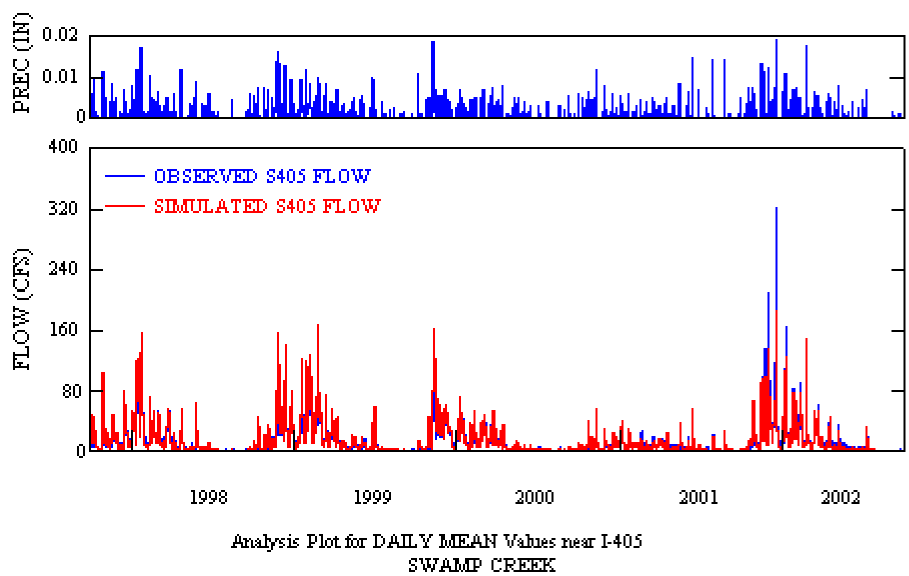


Figure 5.3-2 Snohomish Co Gage near I-405 Flow Duration

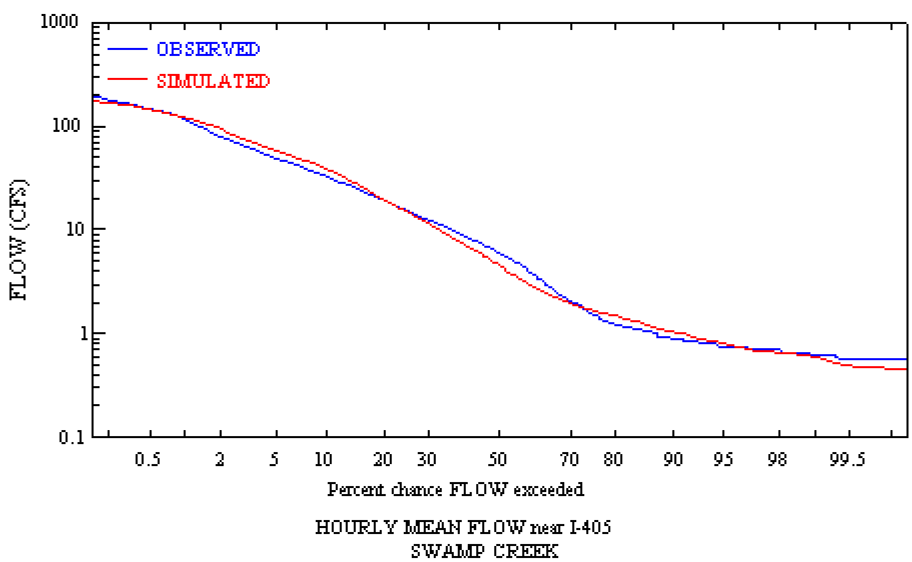


Figure 5.3-3 Snohomish Co Gage near I-405 December 1998 Hourly Flow Time Series

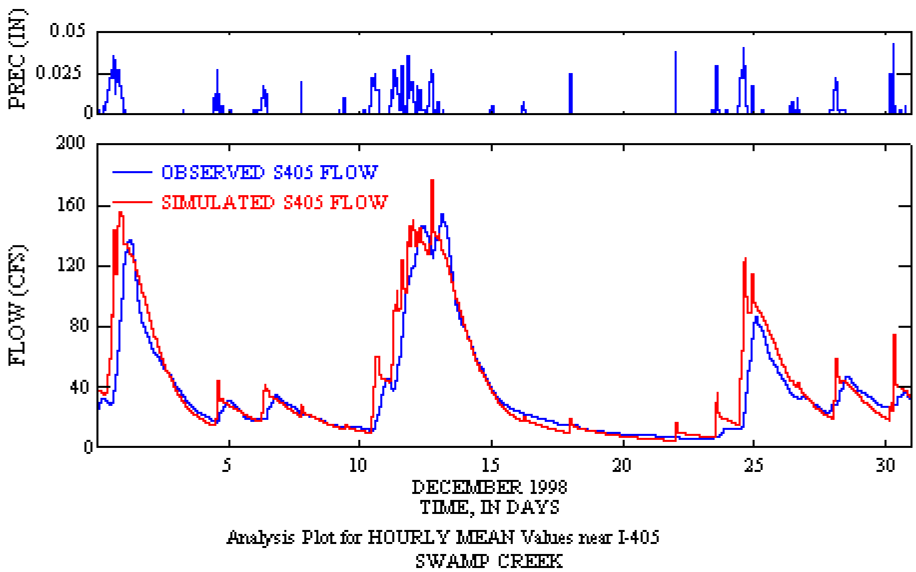


Figure 5.3-4 Snohomish Co Gage near I-405 December 1999 Hourly Flow Time Series

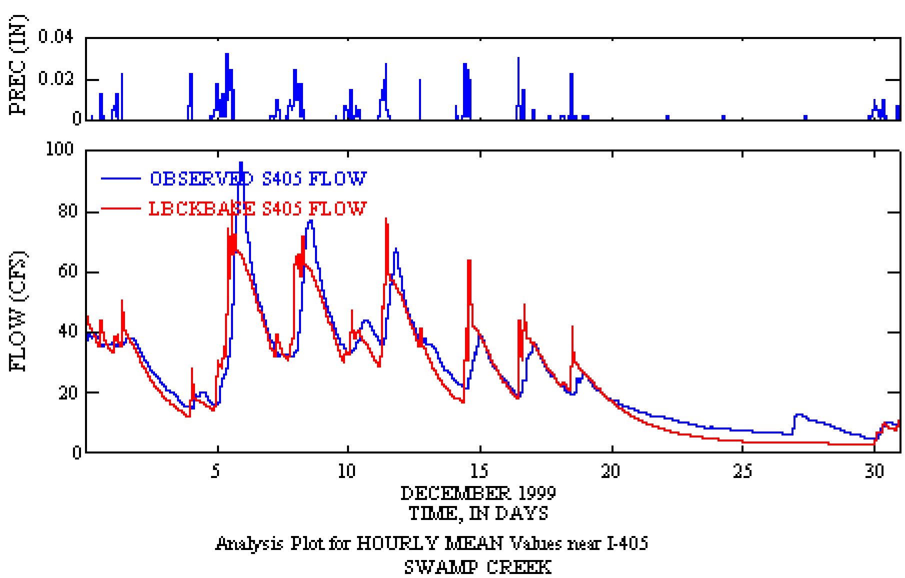


Figure 5.3-5 Snohomish Co Gage near I-405 Monthly Flow Time Series

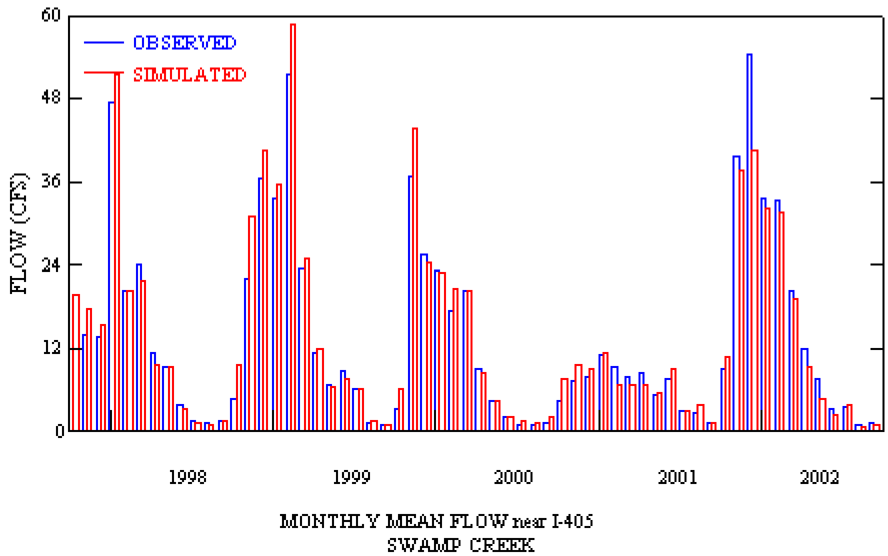


Figure 5.3-6 Snohomish Co Gage near I-405 Scatter Plot

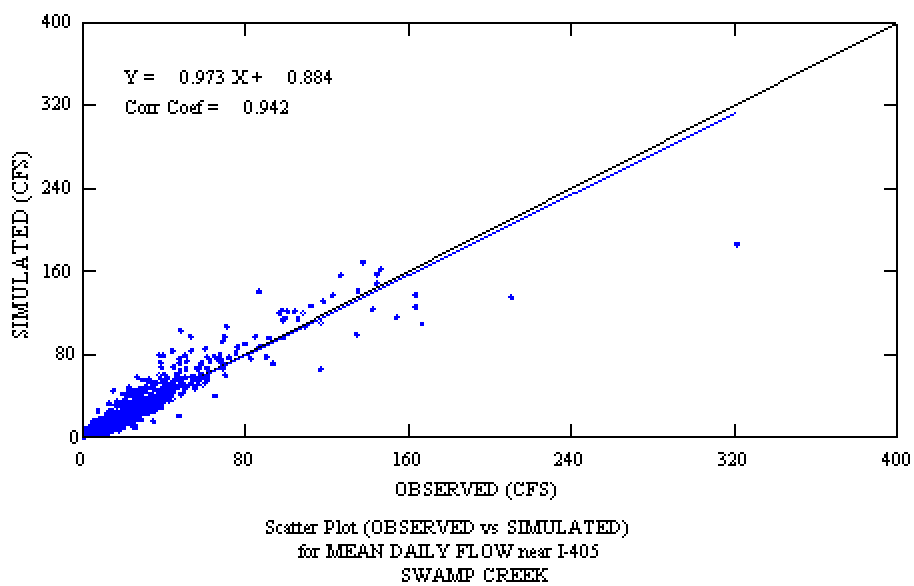


Figure 5.3-7 Snohomish Co Gage near I-405 Residual Plot

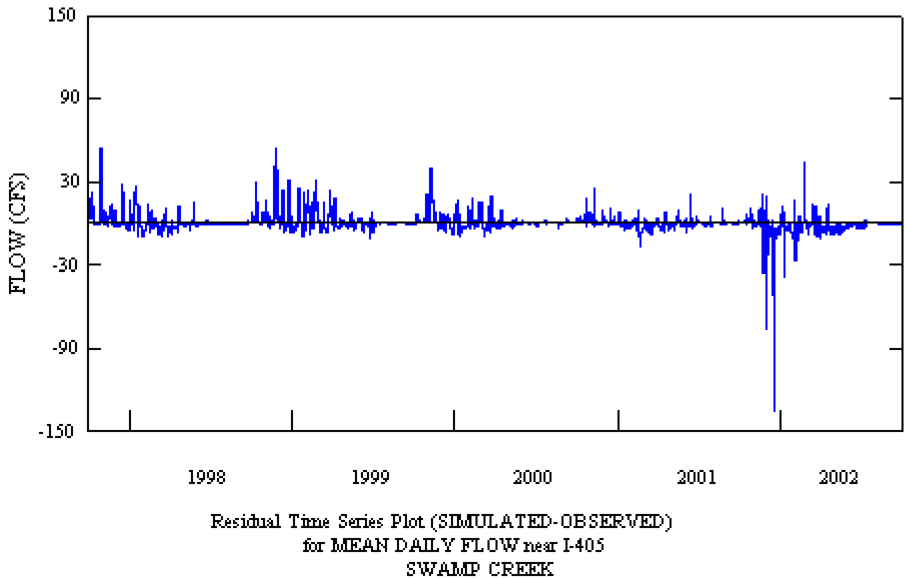


Figure 5.3-8 King Co Gage 56B Daily Flow Time Series

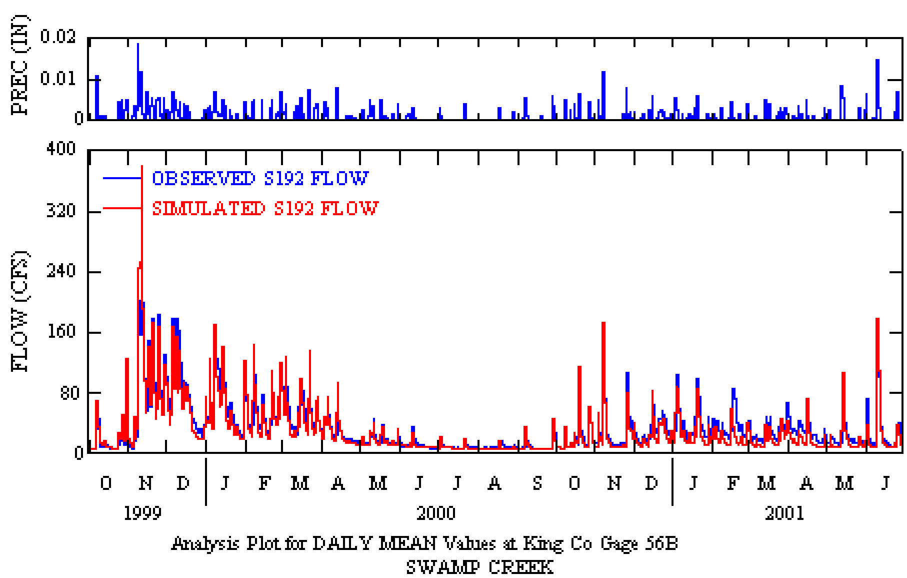


Figure 5.3-9 King Co Gage 56B Flow Duration

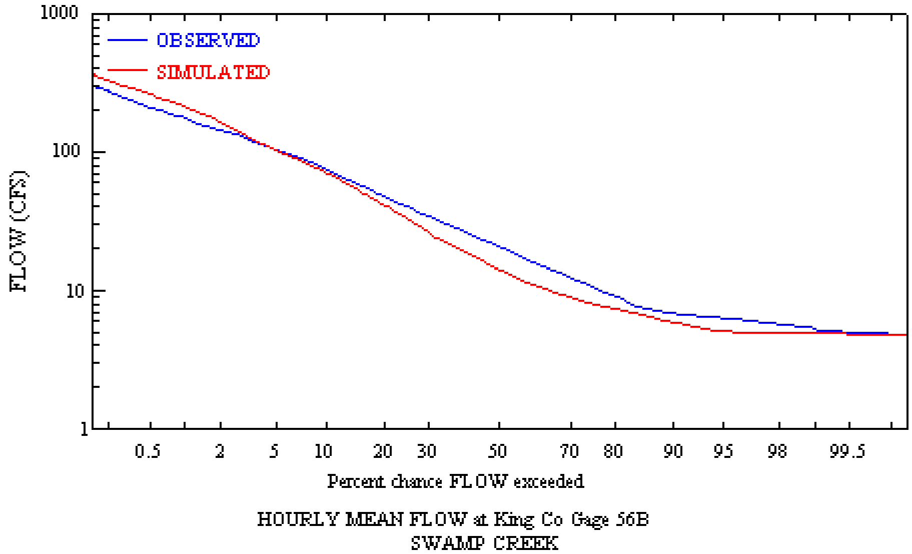


Figure 5.3-10 King Co Gage 56B December 1999 Hourly Flow Time Series

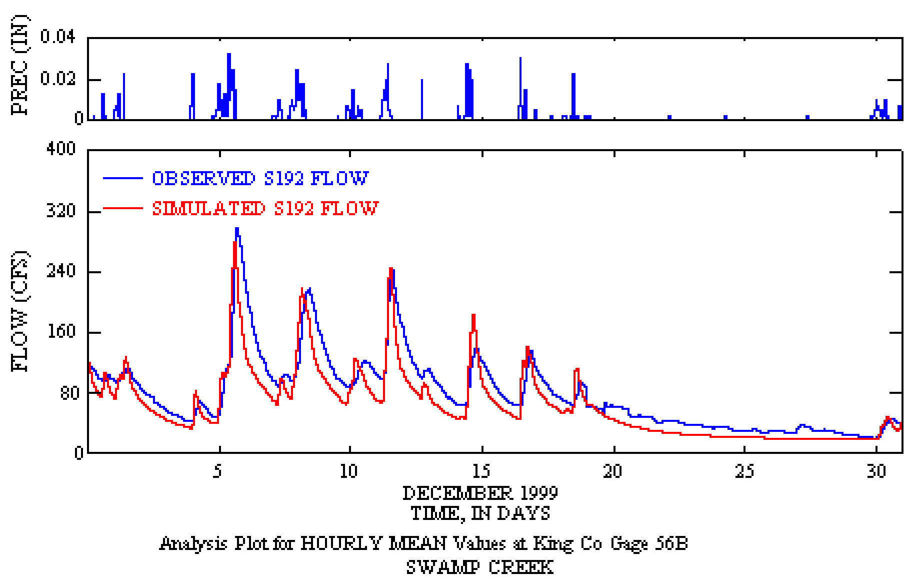


Figure 5.3-11 King Co Gage 56B December 2000 Hourly Flow Time Series

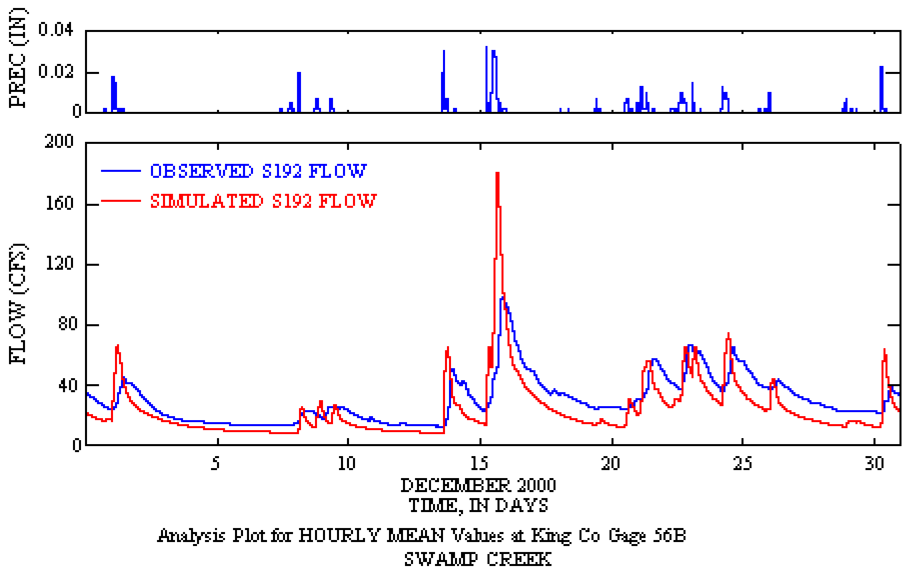


Figure 5.3-12 King Co Gage 56B Monthly Flow Time Series

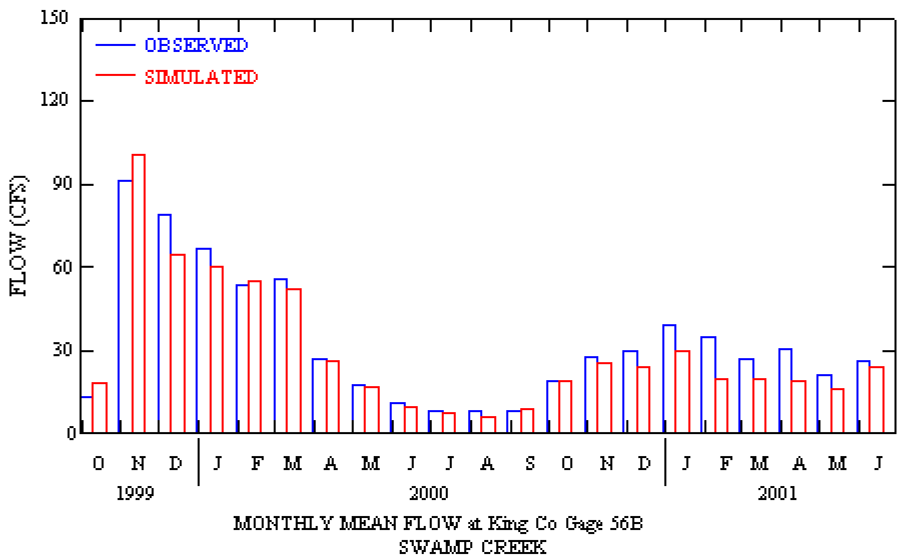
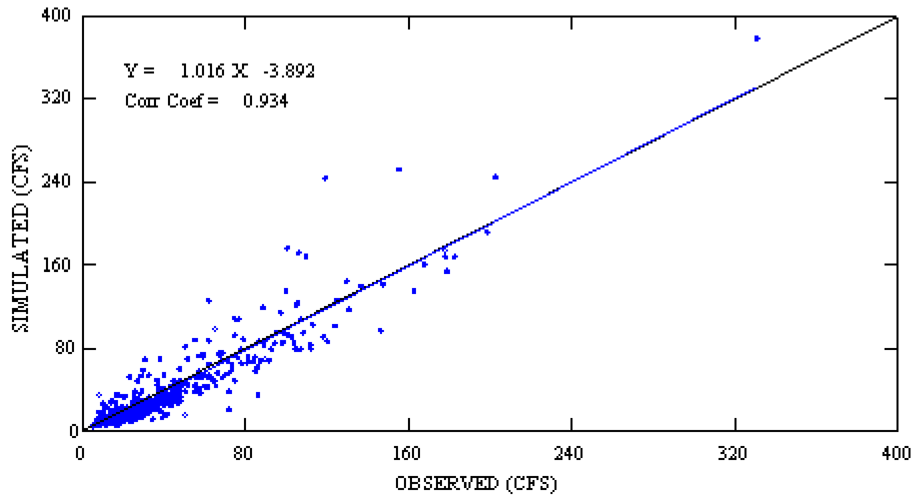
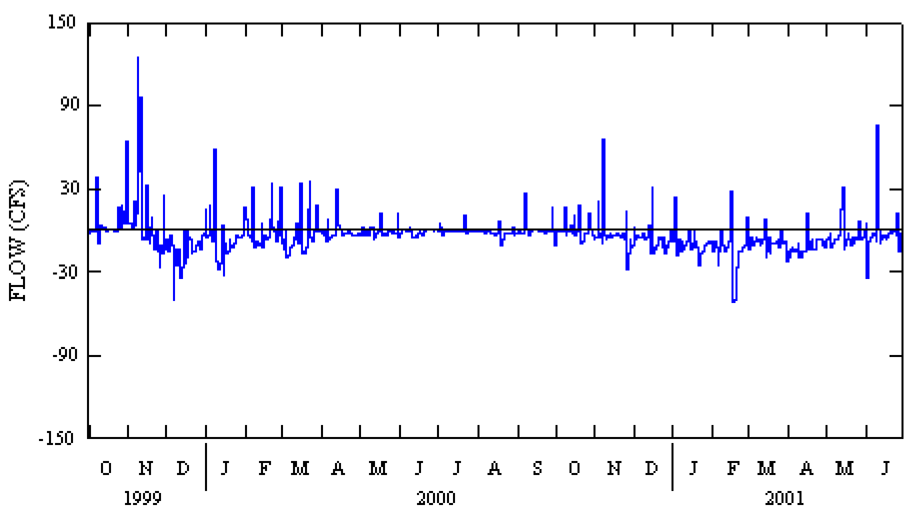


Figure 5.3-13 King Co Gage 56B Scatter Plot



Scatter Plot (OBSERVED vs SIMULATED)
for MEAN DAILY FLOW at King Co Gage 56B
SWAMP CREEK

Figure 5.3-14 King Co Gage 56B Residual Plot



Residual Time Series Plot (SIMULATED-OBSERVED)
for MEAN DAILY FLOW at King Co Gage 56B
SWAMP CREEK

Figure 5.3-75 Snohomish Co Gage near 228th Daily Flow Time Series

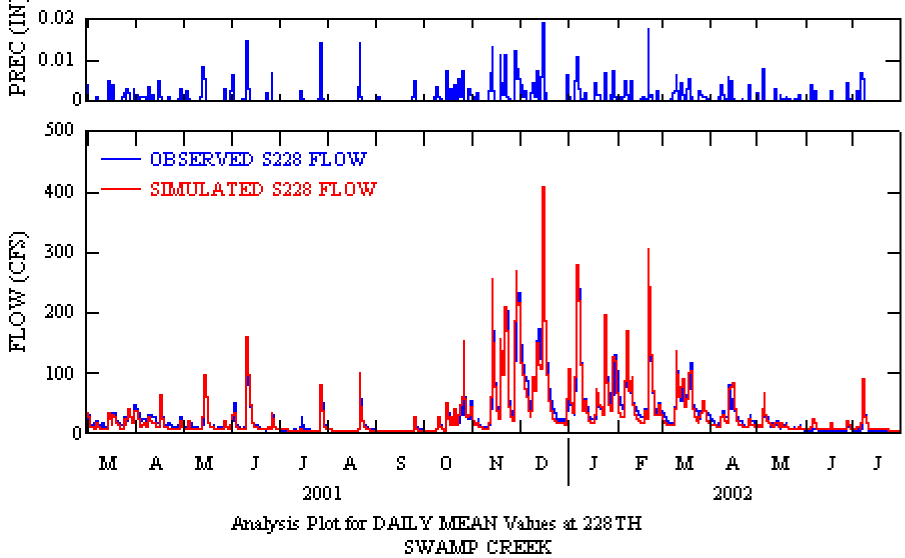


Figure 5.3-16 Snohomish Co Gage near 228th Flow Duration

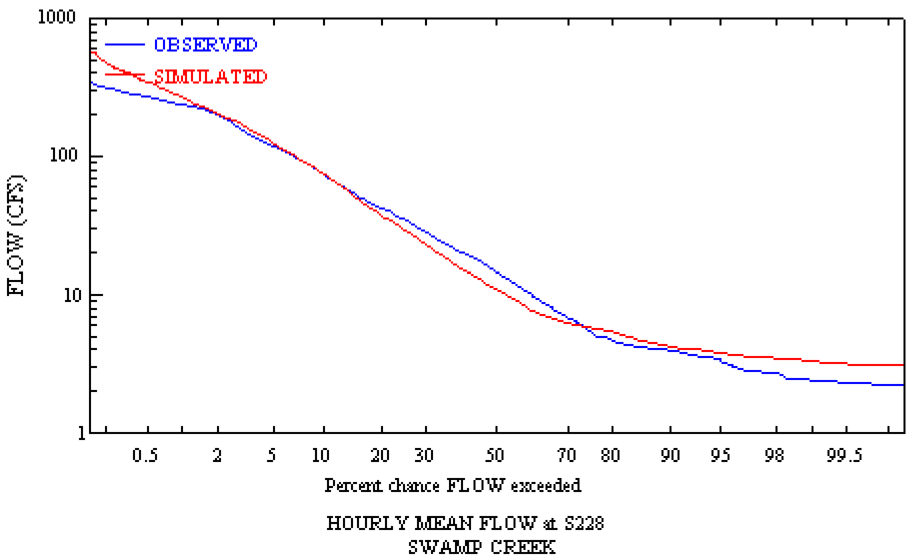
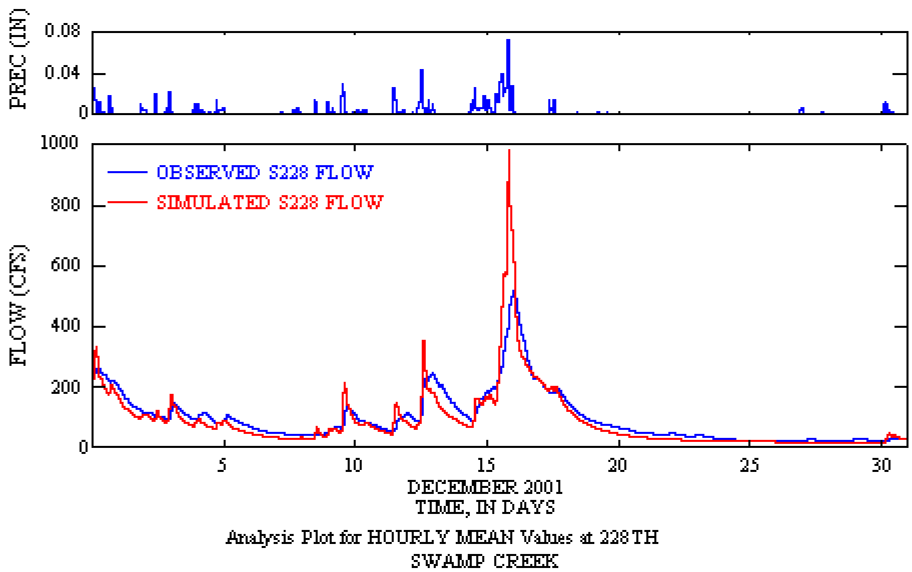


Figure 5.3-17 Snohomish Co Gage near 228th December 2001 Hourly Flow Time Series



In addition to the above comparisons, the water balance components (input and simulated) were reviewed for consistency with expected literature values for the Puget Sound region. This effort included displaying model results for individual land uses for the following water balance components:

- Precipitation
- Total Runoff (sum of following components)
  - Surface Runoff/Overland Flow
  - Interflow
  - Groundwater/Baseflow
- Total Actual Evapotranspiration (ET) (sum of following components)
  - Interception ET
  - Upper zone ET
  - Lower zone ET
  - Baseflow ET
  - Active groundwater ET
- Deep Groundwater Recharge/Losses

Although observed values are not be available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region, as impacted by the individual land use categories. This is a separate consistency, or reality, check with data independent of the modeling (except for precipitation) to insure that land use categories and overall water balance reflect local conditions in the Swamp Creek watershed.

The water balance components for the entire Swamp Creek watershed are shown in Table 5.3-5. These values are weighed based on the contributing area of each Swamp Creek PERLND for the period of record (water years 1998 through 2002). For this time period the mean annual precipitation was 44.63 inches, the total runoff was 22.19 inches, the groundwater flow to the stream was 6.93 inches, the potential evaporation was 24.26 inches, and the actual evaporation was 17.97 inches. These values are all close to or in the range of the expected values, as presented by Dinicola (1990).

Table 5.3-5 Swamp Creek Mean Annual Water Balance (Oct 1997 – Sep 2002)

PERLND:	Till (in)	Out-wash (in)	Saturated (in)	EIA (in)	Watershed Average (in)	Expected (Dinicola, 1990) (in)
Influx						
Rainfall	44.82	43.60	44.32	44.79	44.63	35-50
Runoff						
Surface	5.18	0.09	5.25	36.11	9.80	
Interflow	8.13	0.00	3.98	0.00	5.45	

PERLND:	Till (in)	Out-wash (in)	Saturated (in)	EIA (in)	Watershed Average (in)	Expected (Dinicola, 1990) (in)
Baseflow	4.49	25.72	12.14	0.00	6.93	
Total	17.80	25.81	21.37	36.11	22.19	15-20
GW Inflow						
Deep	7.66	0.54	0.00	0.00	5.08	
Active	4.75	25.41	15.61	0.00	7.19	
Total	12.41	25.95	15.61	0.00	12.27	
Evaporation						
Potential	24.26	24.26	24.26	24.26	24.26	25
Interception Storage	9.35	9.24	9.92	8.66	9.24	
Upper Zone	4.84	1.70	8.63	0.00	3.71	
Lower Zone	5.39	7.14	1.53	0.00	4.56	
Ground Water	0.00	0.00	3.57	0.00	0.13	
Baseflow	0.42	0.26	0.60	0.00	0.33	
Total	20.00	18.35	24.25	8.66	17.97	18-20
Area (ac)	10,241	2,172	566	2,697	15,676	
Area (%)	65.33%	13.85%	3.61%	17.20%	100.00%	

A complete listing of the water balance components by individual PERLND is presented in Appendix A.

A weight of evidence approach is most widely used and accepted when models are examined and judged for acceptance as no single procedure or statistic is widely accepted as measuring, nor capable of establishing, acceptable model performance. Therefore, the calibration relied on numerous statistical tests (e.g., correlation tests, Model Fit Efficiency) and graphical plots (e.g., scatter, time series, frequency) to determine the model's ability to mimic the system.

5.3.1.4 CALIBRATION SUMMARY

Swamp Creek was calibrated at two locations: the Snohomish County gage near I-405 in unincorporated Snohomish County and King County Gage 56B in Kenmore. Statistics and plots were produced for both locations to demonstrate the accuracy of the calibration.

Annual volumes matched well at the Snohomish County gage with an error of 3.9%. The volumes did not match as well at King County Gage 56B.

The hydrology calibration is sufficiently accurate to proceed to the next step in the calibration process for Swamp Creek, which is the calibration of the water quality data.

5.3.2 WATER QUALITY

5.3.2.1 Initial Water Quality Parameter Set

Initial water quality parameters for Little Bear, Swamp, and North Creeks were obtained from previous studies, with emphasis on the recent study to model the generation and delivery of loads from the state of Connecticut to Long Island Sound (ATC and HydroQual, 2001). Additional guidance in understanding local conditions and estimating the variation of pollutant loading and subsurface pollutant concentrations by land use was developed from several local studies of nutrient loading and concentrations in streams (Brett et al., 2002; Prych and Brenner, 1983; King County, 1994) and impacts of urbanization on streams (Booth et al., 2001). Many of the initial parameters were subsequently adjusted during calibration to better represent the water quality conditions in Little Bear, Swamp, and North Creeks. The final calibrated values are provided in the Swamp Creek UCI file, in Appendix A.

5.3.2.2 Water Quality Calibration

The time period of the water quality calibration is October 1992 – September 2001. This period includes the hydrology calibration time period (10/1996 – 9/2001) and utilizes additional water quality data (and meteorological data) that are available at the water quality monitoring stations beginning in 1992 and 1993.

The initial calibration of Swamp Creek was performed simultaneously and in concert with the calibration of North and Swamp Creeks in order to develop general land use-specific water quality parameter sets for use in other parts of the SWAMP and Green-Duwamish Basins. However, subsequent to development of an initial parameter set using all three watersheds, further adjustments were made to the pollutant loading parameters in each watershed to fine-tune the calibration. Similar to the Little Bear Creek watershed, it was assumed that significant impacts of instream processes on pollutant concentrations are unlikely. Therefore, the main emphasis of the calibration and parameter adjustments was the nonpoint loading, primarily via the subsurface (interflow and baseflow) concentrations, but also surface loading associated with surface runoff and sediment. However, the instream parameters were reviewed and adjusted as needed to ensure reasonable values for the specific stream reaches in these watersheds.

A key assumption of this water quality calibration is that the water quality parameters are constant within a land use category, and don't vary with soils (i.e., till, outwash, saturated, rock) or with the four slope classes. This assumes that appropriate differences in the water quality response will be caused by the differences in hydrologic responses that occur as result of the different hydrology parameters used to characterize these soils and slope classes.

5.3.2.3 Summary of Calibration Procedures

As noted earlier, the main goal of water quality calibration is to obtain acceptable agreement of observed and simulated concentrations, while maintaining the instream water quality parameters and processes within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature or based on local experience and guidelines. The use of target nonpoint source loading rates is useful because the water quality concentrations measured at a particular location reflect the combined effects of contributions from multiple land uses, point sources, and instream processes. The target loading rates help to guide the calibration effort and ensure that simulated rates and fluxes from each land use category are reasonable and consistent with literature values and/or local knowledge. These nonpoint loading rates (also known as export coefficients) are highly variable with values ranging up to an order of magnitude, depending on local conditions. Therefore, AQUA TERRA compiled a set of targets with as much applicability to Puget Sound watersheds as possible. Additional data, not specific to Puget Sound were included where necessary to fill data gaps and compare with the locally derived information. These target data are presented in Section 4.3.2.4 of this document.

For most of the constituents, the calibration procedure involved an iterative series of simulations in which the following information was reviewed for the Little Bear, North and Swamp Creeks:

1. Comparison of land-use specific loading rates with the target export coefficients. The simulated loading rates for each land use category were computed as weighted averages based on the amount of land in each slope category of that land use.
2. Plots of simulated (average daily) and observed time series.
3. Statistics (mean, geometric mean, mean of ratio of simulated to observed, mean error, etc.) of corresponding (i.e., values on the same day) observed and simulated data points.
4. Summaries of the relative impacts of various constituent sources and processes within each stream segment.

Based on a review of this information, the monthly variable loading rate parameters for a constituent were adjusted by land use to improve the seasonal agreement for all watersheds and stations. The adjustments were made to try to improve the agreement of concentrations (statistically and graphically) while maintaining reasonable loading rates and reasonable/expected variation among the land use categories. When conflicts arose in the direction of adjustments, priority was given to agreement: 1) at the monitoring stations at the outlets of the three watersheds, since these models will be used primarily to evaluate impacts of total loads delivered to the Sammamish River; and 2) to agreement of concentrations/statistics over target loading rates; and 3) to maintenance of reasonable differences between land use categories. In some cases, if knowledge of local stream conditions was sufficient, instream processes were adjusted to try to improve agreement. For example, algal growth and settling of organics was encouraged in some stream segments to represent the effects of wetland stream channels where lowered nutrient concentrations were observed at nearby downstream monitoring stations. This involved increasing the growth parameter, increasing the availability of light in the channel, reducing the respiration rate of algae, and increasing the settling rates of organics species.

5.3.2.4 Calibration Discussion and Results

The results of the calibration are presented on the following pages. Table 5.3-6 shows the average annual (over the nine year simulation period) loading rates in pounds/acre/year for nitrogen species and compares them with the target rates. Table 5.3-7 shows the same information for phosphorus species and sediment. Table 5.3-8 presents the mean simulated and observed concentrations on sampling dates for the various constituents, and the ratio of the means. Table 5.3-9 shows the average (and range) of simulated/observed concentration ratios for all Swamp Creek Stations. Finally, Figure 5.3-8 through Figure 5.3-18 show the time series plots of simulated daily and observed water quality constituent concentrations for the primary (outlet) station in Swamp Creek, i.e., Station 0470. The following discussion is focused by constituent.

Water temperature calibration was done first, so that the various instream processes that are dependent on temperature would be modeled with reasonable temperature conditions. Initial temperatures were generally (but not always) oversimulated by up to 3 C in summer and undersimulated slightly in winter. Temperature adjustments were made as follows:

- Stream shading was checked with any available information; and adjusted to improve the agreement.
- The parameters that determine the temperature of runoff from pervious and impervious land areas were adjusted seasonally.
- Since these are shallow streams, the temperature of the ground beneath the stream was adjusted seasonally to increase the effect of heat transfers via this pathway. Generally, the water temperature is well calibrated in Swamp Creek as evidenced in Figure 5.3-8 and the statistical information shown below, with occasional summertime oversimulations in the comparisons of daily average data apparent at all four of the monitoring stations (shown in Figure 4.3-1 and Appendix B).

Sediment - Target sediment loadings to the stream channel were estimated for each land use category from the available literature data. Table 3.2-1 lists target loading rates that were developed for calibrating the nonpoint sediment loadings within the Swamp Creek and other Puget Sound watersheds. The model categories are a function of soil type and slope class, in addition to land use, and therefore the loading rates should also be variable within a given land use to reflect the combined erodibility of the soil matrix and slope class.

KRER and KSER are the primary sediment erosion calibration parameters in HSPF. They governing detachment of soil particles by raindrop impact on the land surface and the subsequent transport of these particles by overland flow, respectively. KRER is usually estimated as equal to the erodibility factor, K, in the USLE, and then adjusted in calibration, while KSER is primarily evaluated through calibration and past experience. During the calibration of the Swamp Creek watershed model, KRER was set to reflect the variability of the soil types while KSER was adjusted to achieve the expected range of loading rates amongst the land use categories. The loading rates by slope class were primarily dictated by the overland flow rates generated by the respective class. The parameters for vegetal cover (COVER) and atmospheric fallout (NVSI) were not adjusted during the calibration process, but assumed to be constant, based on the type of land use.

Once the sediment loading rates were calibrated to provide reasonable loadings to the stream channel, the sediment calibration focused on the channel processes of deposition, scour, and transport. The sediment calibration involved iteratively performing several steps to determine the model parameters and appropriate adjustments needed to insure a reasonable simulation of the sediment transport and behavior of the channel system. The steps performed during the calibration were as follows:

1. Divided the nonpoint sediment loads into sand, silt, and clay fractions. For the Swamp Creek model, the fractionation of the sediment was assumed to be: 5% sand, 70% silt, and 25% clay.
2. Ran the model to calculate bed shear and establish scour and deposition patterns – HSPF calculates the shear stress (TAU) as a function of the reaches hydraulic radius, slope, and density of water. For the silt and clay (i.e. cohesive) fractions, shear stress calculations are compared to user-defined critical, or threshold, values for deposition and scour. Thus, knowing the range of TAU values a reach experiences is critical in establishing the expected scour and depositional patterns.

3. Estimated initial parameter values and storages for all reaches. The key sand parameters are the coefficient (KSAND) and exponent (EXPSND) in the power function equation that defines sand transport, along with the sand particle characteristics. Initial KSAND and EXPSND values were estimated, and the sand particle characteristics were set at typical values found in the literature. The key silt and clay parameters are the critical bed shear threshold values for scour (TAUCS) and deposition (TAUCD), and the associated particle characteristics. Initial values for TAUCS and TAUCD were estimated on a reach by reach basis based on the simulated TAU values in each reach. In the absence of any channel bed composition data, the initial composition of each of the channel beds was assumed to be 65% sand, 15% silt, and 20% clay.
4. Historical information was not available to describe how each of the modeled streambeds were changing over time; therefore, the primary parameters for scour, deposition and transport were mainly adjusted to achieve channels that were stable with time (i.e., over the calibration period) for each of the size fractions.
5. Calibration was performed at Station 0470, located near the outlet of the watershed and operated by King County, along with the Snohomish County gages located at Lockwood Road, 148th Street SW, and Center Road. The Snohomish County sites served primarily as consistency checks of the overall sediment budgets and loading rates. The frequency and overall number of data points did not support any rigorous statistical tests. Therefore, the comparisons primarily consisted of graphical plots and simple statistics (e.g., comparison of means, geometric means, ratio of simulated vs. observed). The primary parameters for scour, deposition and transport were further adjusted to achieve agreement between simulated and observed concentrations, while maintaining the desired bed behavior and a reasonable distribution of sand, silt, and clay within the beds and water column.

Nitrogen Species - Calibration of nitrate and ammonia was largely done by adjusting the interflow and groundwater concentrations (and ammonia surface loading factors) by land use based on the relative amounts of land in each of the three watersheds (Little Bear, North, Swamp), until the errors were minimized at the three outlet stations. The agreement was fairly good for nitrate at the two downstream stations in Swamp Creek, where local effects of significant groundwater losses are minimized. The nitrate levels in the upper basin, i.e., at the 148th Street SW (SCLU), and Center Road (SCMD) stations where groundwater losses are significant, were difficult to improve by land use-specific adjustments. Ammonia concentrations, which are available only at the outlet stations, showed reasonably good statistical agreement over the three watersheds, after adjustment of loading parameters by land use. Adjustments were made to the overall organics loading to improve the total nitrogen agreement at the outlets. These adjustments, plus the fact that total nitrogen concentrations are largely determined by nitrate, resulted in good agreement for total nitrogen, both statistically and graphically. Algal growth and other biological processes have a relatively small impact on the nitrogen behavior.

Phosphorus Species - Orthophosphate concentrations were calibrated by adjusting the land use-specific interflow and groundwater concentrations and the surface parameters (potency factors) seasonally to achieve a fit. This was done in such a way to reproduce the seasonal pattern, which is apparently determined primarily by the SRP in groundwater, and the dilution of this SRP by the higher rainfall-driven flows (interflow) in the winter. The graphical and statistical measures indicate it is fairly well calibrated. Note that storms produce spikes of PO4, which is primarily from the surface-generated particulate P. The oversimulation of TP at the two upper stations in Snohomish County is partially caused by the method used in the hydrology calibration to remove the groundwater contributions in the upper basin. Another possible source of error may be the assumed differences in phosphorus concentrations between interflow and groundwater.

Dissolved oxygen - The initial simulations produced fairly good agreement with the observed DO, because in relatively low impact streams and watersheds such as Swamp Creek, the principal determinant of DO is water temperature, as opposed to algal growth and organic matter decay. Once the water temperature was fine-tuned, DO agreement was further improved as shown by the graphical and statistical information shown here for the Swamp Creek stations. The time series plot for the 148th Street SW (SCLU) station shown in Appendix B shows mixed results, and may be related to the low baseflow in this part of the watershed. The graph of DO shown for the Center Road station (SCMD) indicates that the streamflow in this area during dry periods is consistently below the HSPF threshold (depth = 2 inches) for computation of water quality processes, including reaeration. This results in the anomalous excursions near 7mg/L which occur in the summer of each year. The reason for the large disagreement at all three of the Snohomish County stations in 1993 is unknown.

Alkalinity was calibrated primarily by adjusting subsurface (interflow and groundwater) concentrations to obtain the seasonal variation exhibited at the outlet station while maintaining appropriate differences between land uses. Initial values and the land use variation were based on the monitoring data and very limited land use-specific sampling from Newaukum Creek presented by Prych and Brenner (1983). The graphical and statistical agreement in Swamp Creek was good (e.g., average ratio of simulated to observed concentrations = 0.98). One difficulty noticed in the initial calibration runs was the effect of storms that resulted in both sharp upward spikes (increases) and sharp downward spikes (dilutions) in close proximity to each other in time. Since pH is very sensitive to alkalinity, large variations in predicted pH resulted from this behavior. However, the observed pH data at the three upstream stations and the alkalinity data at the outlet station suggest that there can be significant variation over relatively short periods. Furthermore, the sensitivity of pH to alkalinity provided a more accurate indicator of error in the alkalinity calibration, and therby facilitated an improved calibration over that provided solely by alkalinity comparisons.

pH was calibrated to data at the three Snohomish County stations on Swamp Creek because there were no monitoring data at the outlet station (0470). The calibration focused on attaining reasonable values and seasonal variation, based on experience and the monitoring data in both North and Swamp Creeks. The pH was sensitive to alkalinity as was noted above. It was also sensitive to total inorganic carbon (TIC) concentration. Initial simulated TIC concentrations from runoff (< 1 mg/L) resulted in unreasonably high values of predicted pH (~11). Based on fundamental chemical equilibrium equations relating pH, alkalinity, and TIC, it was determined that the observed alkalinity and pH levels would necessitate concentrations of TIC in the range of 16-19 mg/L, which are unattainable with the existing formulation in HSPF. Therefore, the existing algorithm was used as an indicator or index to the TIC loading, but the actual values were adjusted upwards by a constant factor of 40 to attain the necessary TIC to compute pH values that are in line with observations in Swamp and North Creeks. The statistical and graphical evidence shown in Tables 4.3-3 and 4.3-4 and Appendix B suggests an adequate representation of pH in Swamp Creek.

E-Coli is extremely variable and difficult to predict. One reason for this is that many of the larger loadings of bacterial material probably occur during somewhat random but “catastrophic” events, such as CSO events or other failure of human (and agricultural) waste disposal facilities, which can produce large, unpredictable concentrations. Examination of the observed E-Coli data suggests relatively little quantitative correlation with the storms and little seasonal variation. Therefore, efforts were made to attain general agreement between the simulated concentrations and the bulk of the observed values, which are on the order of 200 CFUs/100 mL as opposed to the arithmetic mean (~600), which is strongly biased by several extreme values in the data record. Initial attempts to calibrate to these extremes in the observed data, e.g., by large increases in the surface runoff of E-Coli, produced unreasonably large loadings.

Table 5.3-6 Average Annual Nitrogen Loadings

	Constituents (Average lbs/acre/year loadings)							
	Nitrate-N		Ammonia-N		Organic N		Total N	
Land Category	**Target**	**Simulated**	**Target**	**Simulated**	**Target**	**Simulated**	**Target**	**Simulated**
Forest	1.4	2.4	0.2	0.05	0.4	1.9	2.0	4.4
Pasture/Ag	9.0	42.	1.3	0.39	2.5	16.	13.	58.
Forest Residential	4.2	2.8	0.6	0.06	1.2	2.2	6.0	5.0
Low Density Residential	4.9	4.5	0.7	0.2	1.4	2.3	7.0	7.0
High Density Residential	6.3	4.5	0.9	0.3	1.8	2.3	9.0	7.1
Commercial/ Industrial	4.9	9.3	0.7	0.4	1.4	2.7	7.0	12.

Table 5.3-7 Average Annual Phosphorus and Sediment Loadings

	Constituents (pounds/acre/year loadings)							
	Orthophosphate-P		Organic P		Total P		Sediment (tons)	
Land Category	Target	Simulated	Target	Simulated	Target	Simulated	Target	Simulated
Forest	0.05	0.03	0.07	0.11	0.12	0.14	0.04	0.03
Pasture/Ag	0.6	4.5	0.7	0.9	1.3	5.4	0.08	0.09
Forest Residential	0.09	0.05	0.16	0.12	0.25	0.18	0.06	0.06
Low Density Residential	0.2	0.13	0.3	0.13	0.5	0.26	0.14	0.13
High Density Residential	0.35	0.16	0.45	0.13	0.7	0.3	0.16	0.17
Commercial/ Industrial	0.5	1.1	0.9	0.2	1.4	1.3	0.36	0.33

Table 5.3-8 Mean Simulated vs. Observed Concentrations on Sample Dates

	Swamp Creek at Station 0470			Swamp Creek at Lockwood Road (SCLD)			Swamp Creek at 148th Street SW (SCLU)			Swamp Creek at Center Road (SCMD)		
Constituent	Sim.	Obs.	* MDR	Sim.	Obs.	* MDR	Sim.	Obs.	* MDR	Sim.	Obs.	* MDR
Water Temperature (C)	9.54	9.83	0.98 (135)	10.17	10.59	0.96 (104)	8.86	9.53	0.91 (89)	8.48	8.35	0.99 (33)
Suspended Sediment	11.6	9.3	0.84 (138)	11.5	22.0	1.19(67)	7.7	6.0	1.13 (55)	7.2	6.8	0.85 (18)
Dissolved Oxygen	9.8	10.0	0.99 (133)	11.2	10.9	1.05(103)	11.2	9.3	1.28 (89)	10.7	9.2	1.21 (33)
Nitrate-Nitrite as N	0.79	0.86	1.00 (136)									
Ammonia as N	0.027	0.031	1.15 (107)									
Total Nitrogen	1.10	1.25	0.91 (131)									
Orthophosphate as P	0.026	0.029	1.02 (135)									
Total Phosphorus	0.058	0.066	0.99 (155)	0.062	0.052	1.29(104)	0.054	0.031	2.45(88)	0.05	0.04	1.86 (30)
Alkalinity as $CaCO_3$	60.7	63.6	0.98 (63)									
pH				7.42	7.57	0.98(103)	6.97	6.99	1.00(88)	7.13	7.15	1.00(33)
EColi (CFUs/100 ml)	541	599	1.21 (41)									

Table 5.3-9 Average and Range of Simulated/Observed Concentration Ratios for all Swamp Creek Stations

Constituent	Average	Range
Water Temperature (deg C)	0.96	0.30 – 3.33
Suspended Sediment	0.98	0.01 – 24.0
Dissolved Oxygen	1.10	0.73 – 2.49
Nitrite-Nitrate as N	1.00	0.38 – 2.53
Ammonia as N	1.15	0.10 – 5.74
Total Nitrogen	0.91	0.44 – 2.09
Orthophosphate as P	1.02	0.24 – 3.72
Total Phosphorus	1.48	0.16 – 9.17
Alkalinity as $CaCO_3$	0.98	0.74 – 1.71
EColi	1.21	0.07 – 5.58

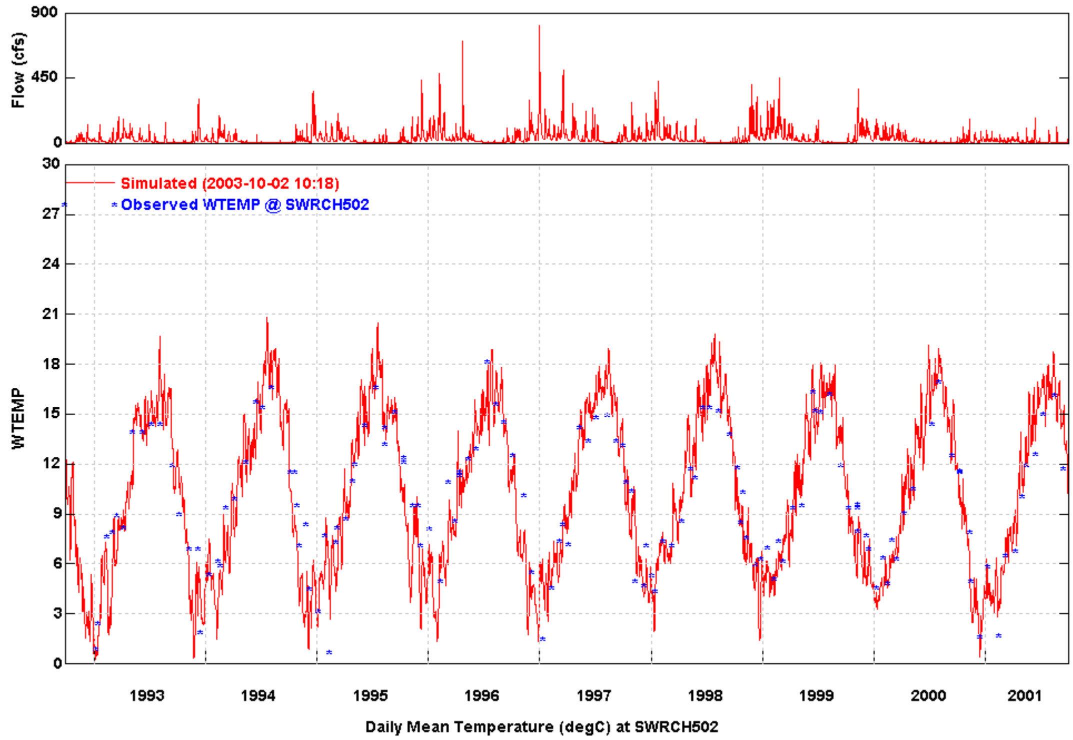


Figure 5.3-8 Observed and Simulated Daily Water Temperature for Swamp Creek at Station 0470

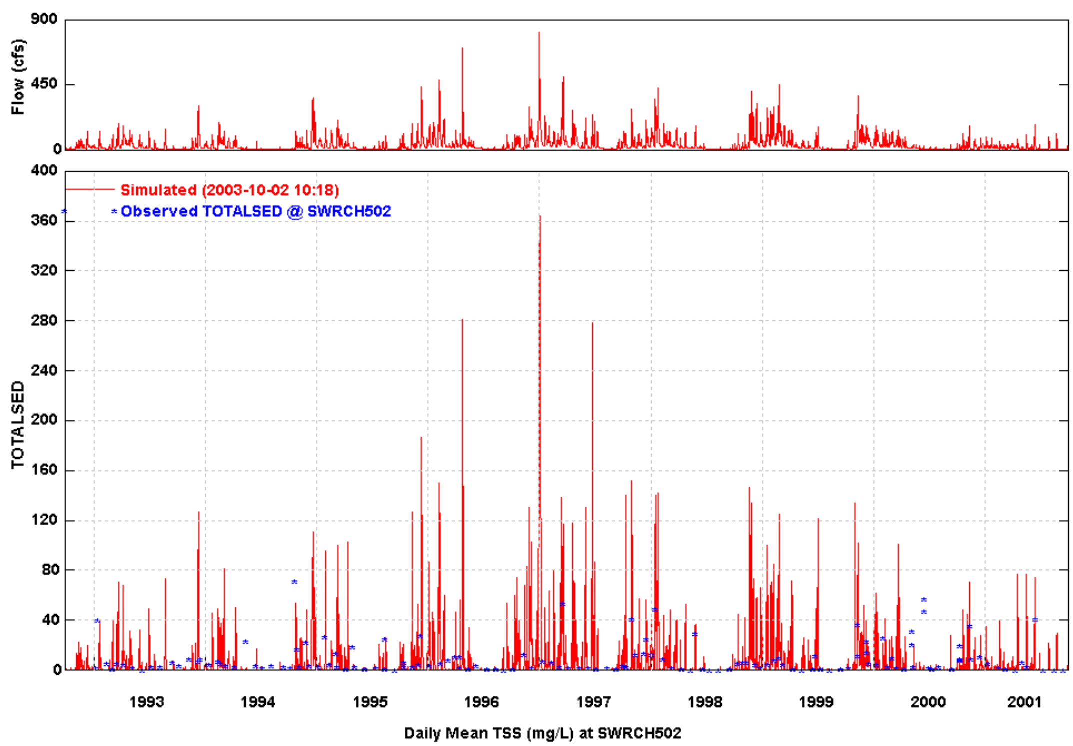


Figure 5.3-9 Observed and Simulated Daily Suspended Sediment Concentrations for Swamp Creek at Station 0470

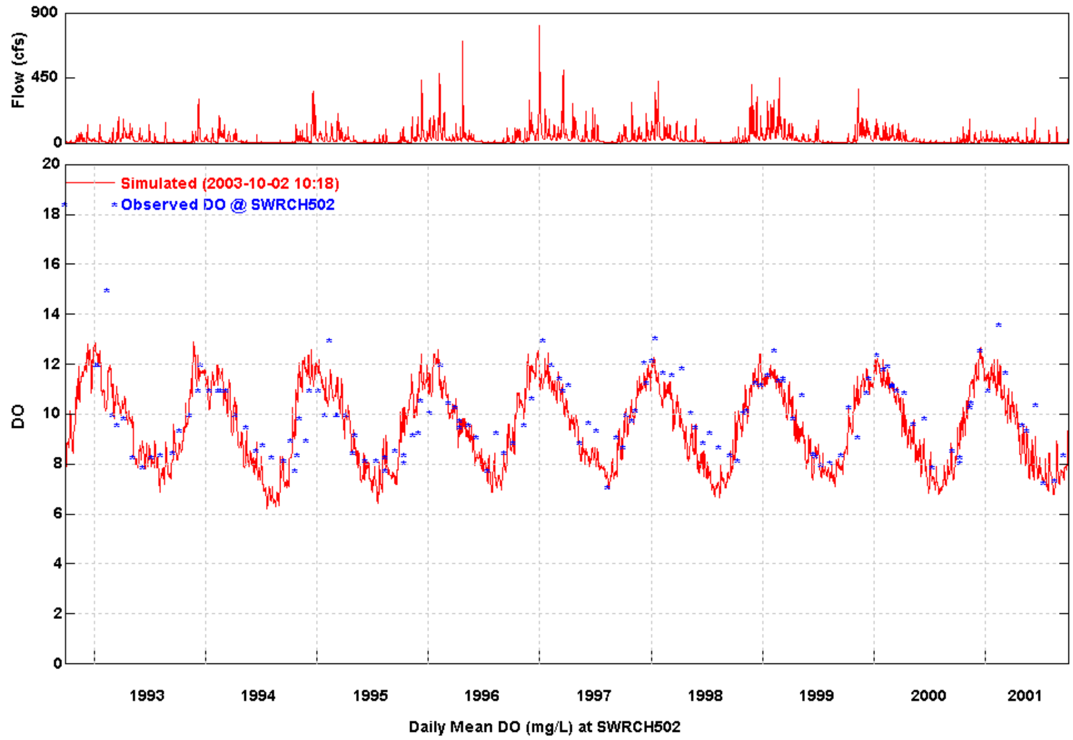


Figure 5.3-10 Observed and Simulated Daily Dissolved Oxygen Concentrations for Swamp Creek at Station 0470

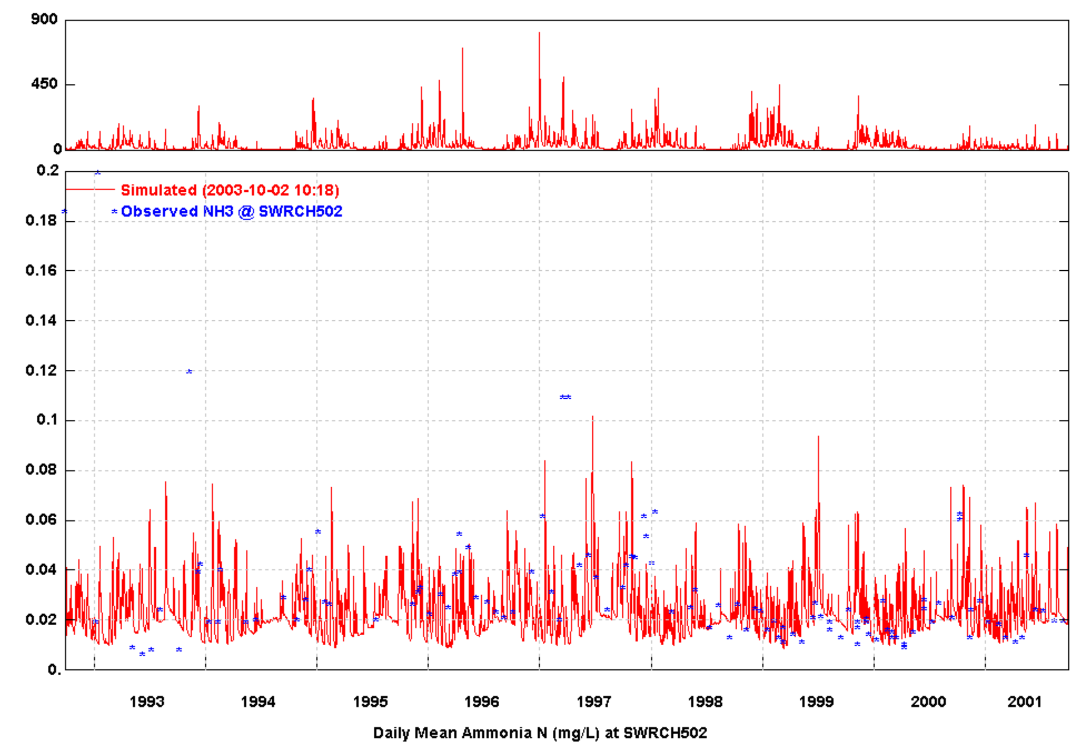


Figure 5.3-11 Observed and Simulated Daily Ammonia Concentrations for Swamp Creek at Station 0470

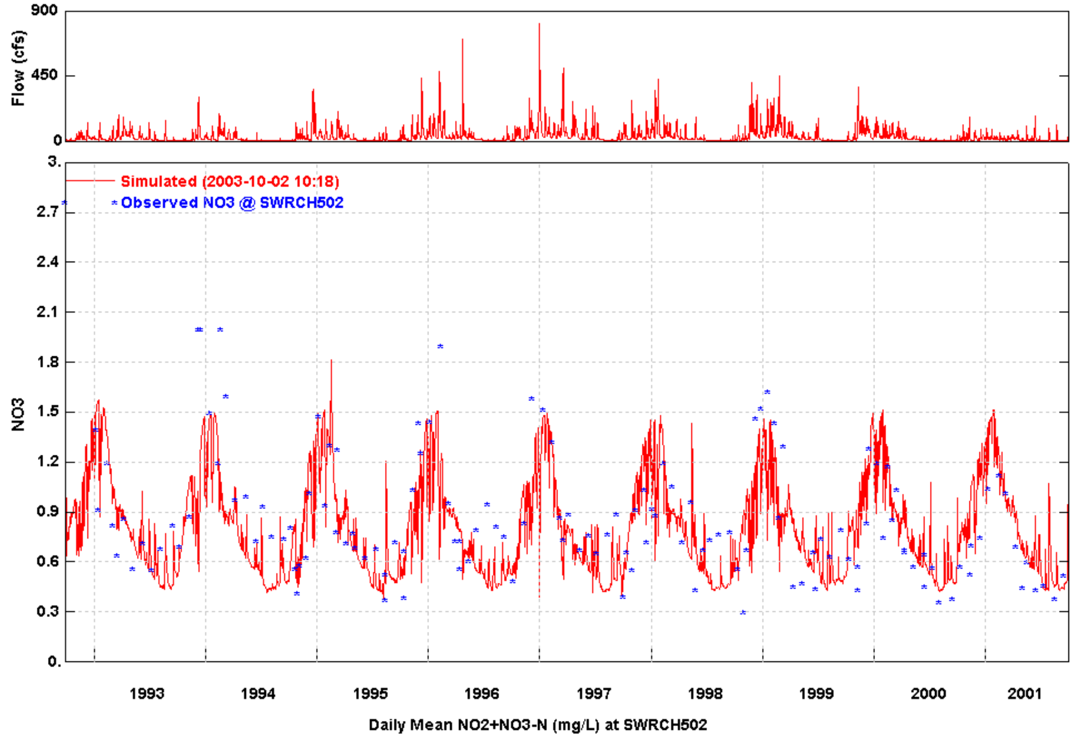


Figure 5.3-12 Observed and Simulated Daily Nitrate Concentrations for Swamp Creek at Station 0470

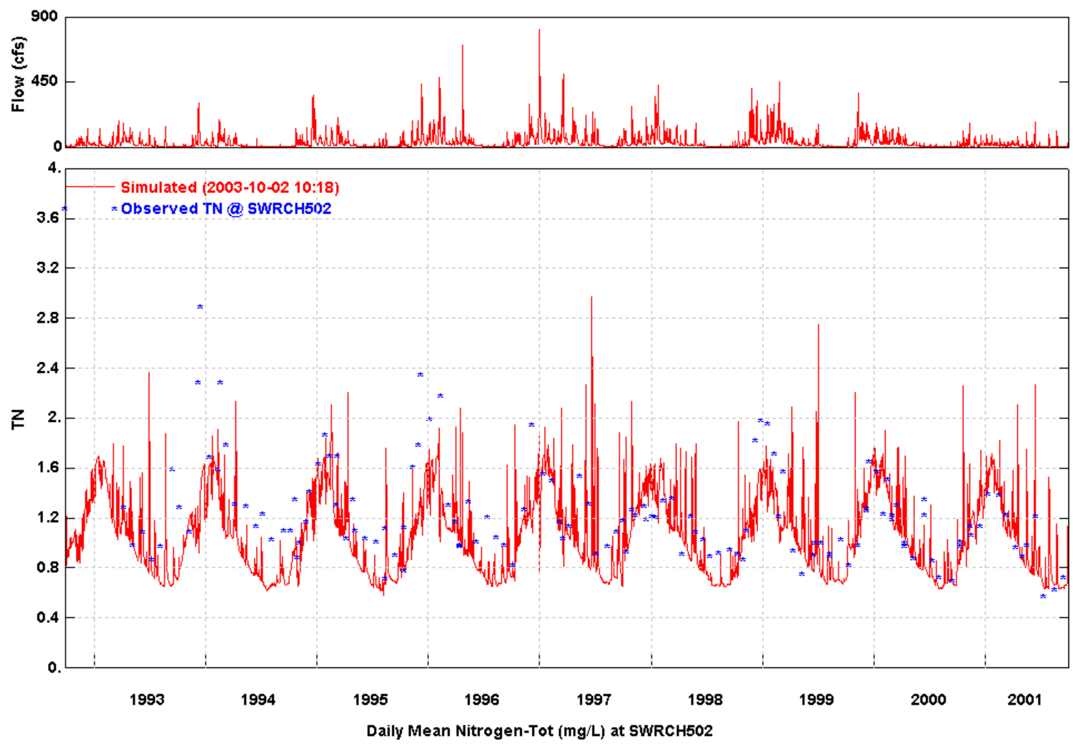


Figure 5.3-13 Observed and Simulated Daily Total Nitrogen Concentrations for Swamp Creek at Station 0470

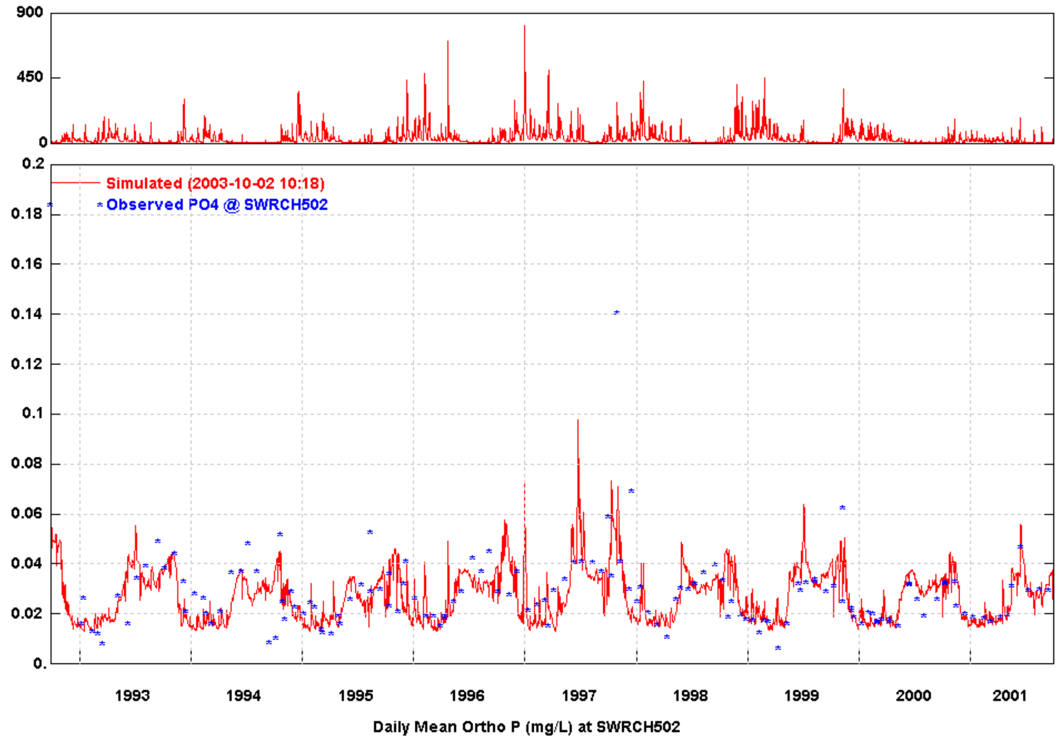


Figure 5.3-14 Observed and Simulated Daily Orthophosphate Concentrations for Swamp Creek at Station 0470

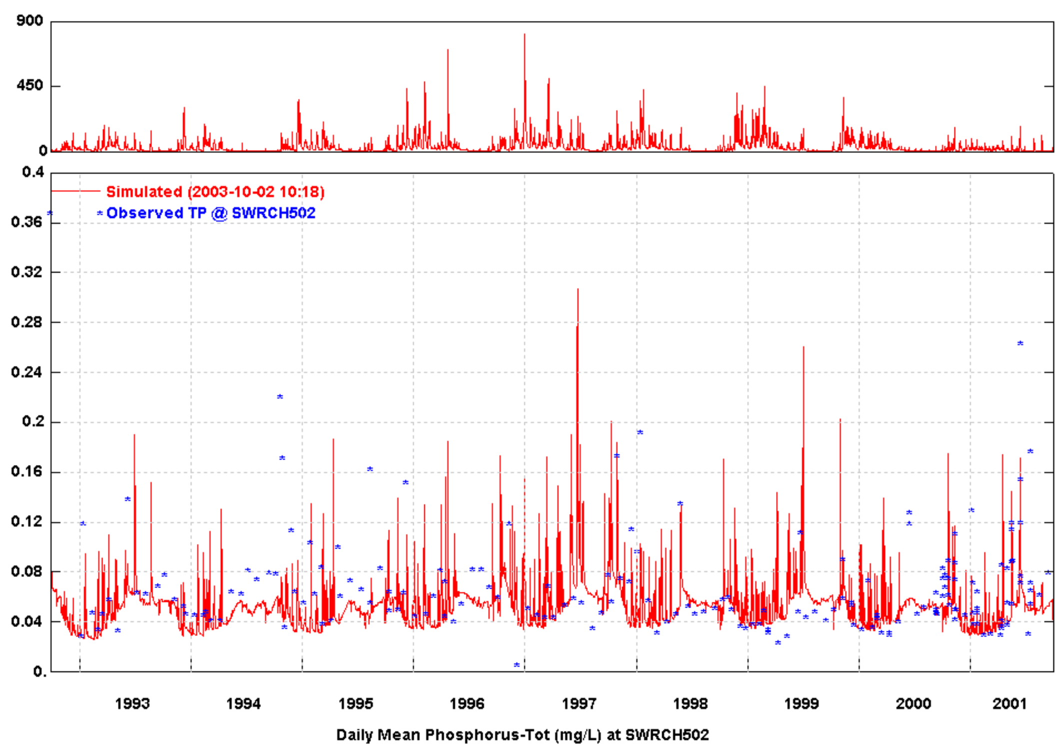


Figure 5.3-15 Observed and Simulated Daily Total Phosphorus Concentrations for Swamp Creek at Station 0470

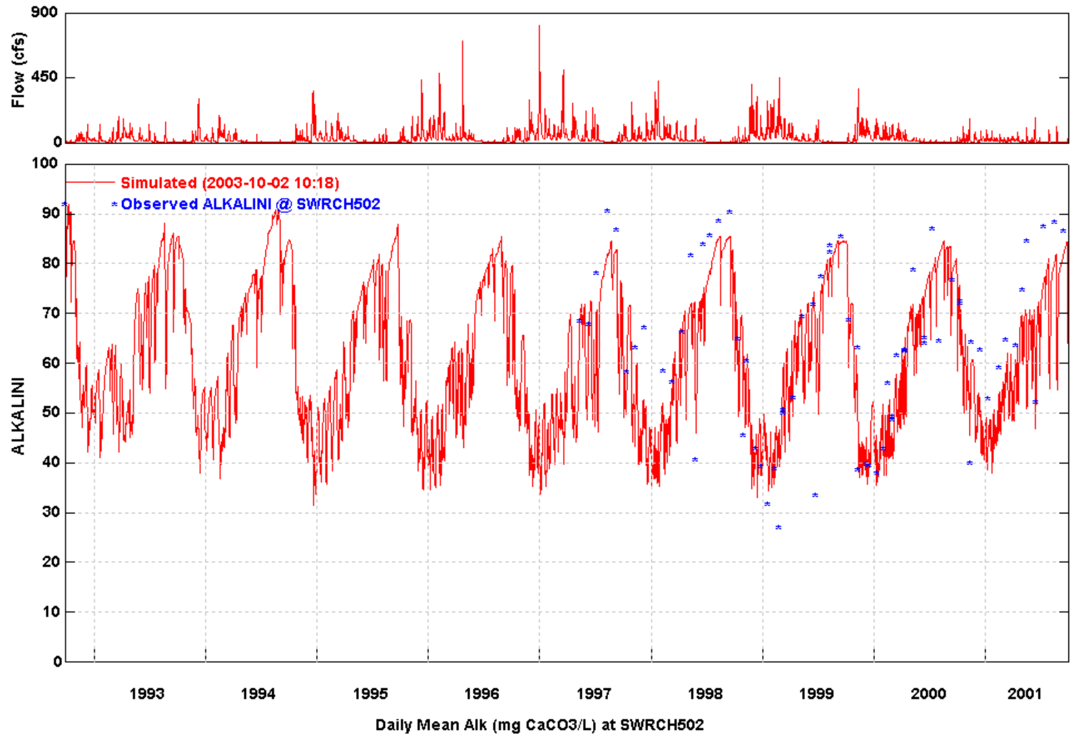


Figure 5.3-16 Oserved and Simulated Daily Alkalinity Concentrations for Swamp Creek at Station 0470

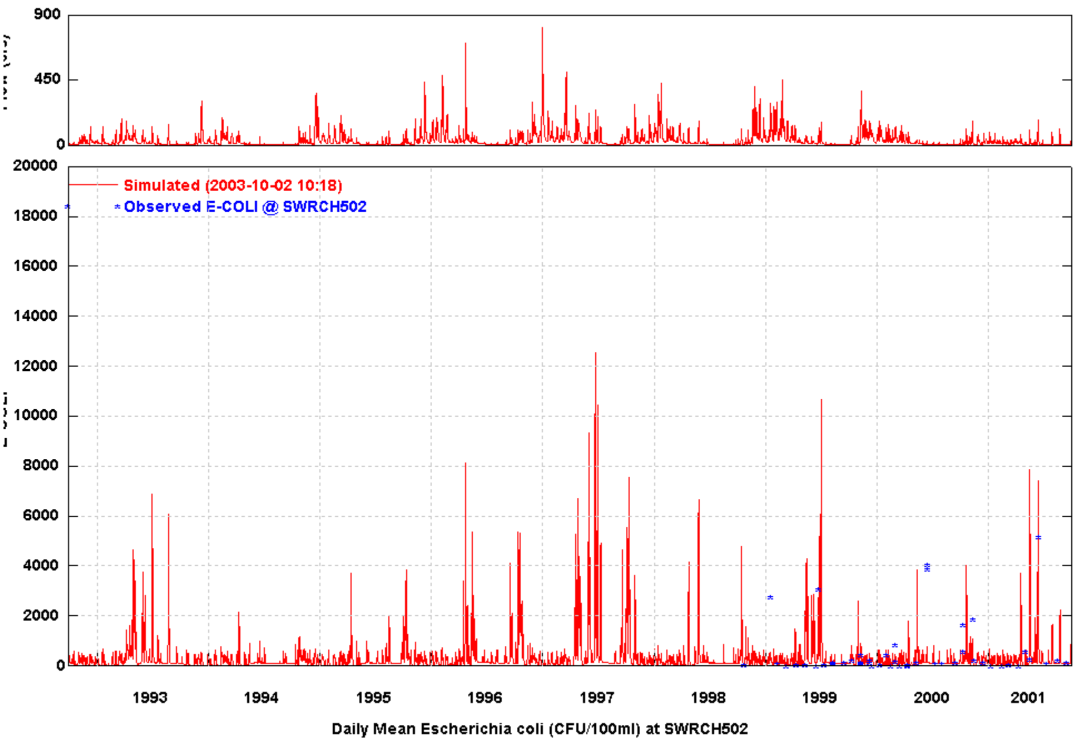


Figure 5.3-17 Observed and Simulated Daily EColi Concentrations for Swamp Creek at Station 0470

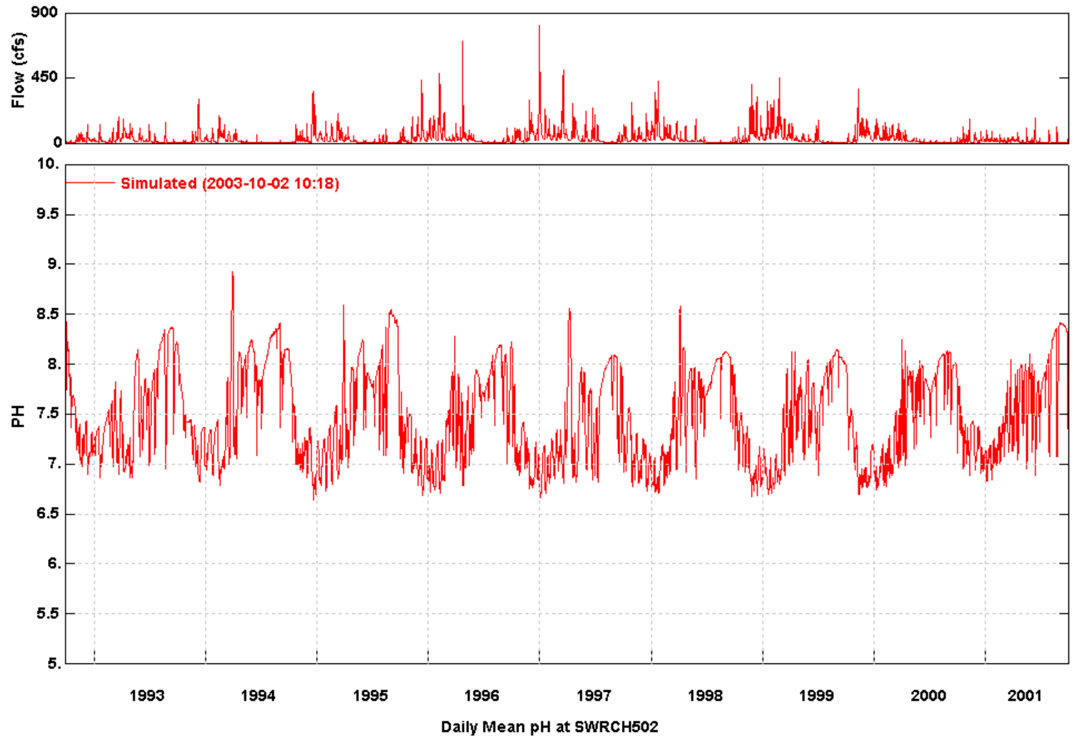


Figure 5.3-18 Simulated Daily pH Values for Swamp Creek at Station 0470

5.3.2.5 Unresolved Calibration Issues

At the current time, several issues related to this model are not complete or should at the least be considered further. One of these issues is addressed below, and others should be noted in reviews by County staff.

- While the instream water quality (biological) processes are currently operating in the model, they are not having much impact. This is partly because of the absence of any organic or other monitoring data which indicates their impact (e.g., on nutrient or oxygen concentrations) or which can be used to calibrate them. This issue should be investigated by AQUA TERRA (with guidance by the County) to determine whether additional emphasis on characterizing these processes is useful for these three watersheds.

5.4 MODEL LINKAGES

The Sammamish River Model (CE-QUAL-W2) requires a subset of the following quantities/constituents:

- Flow (m^3/s)
- Temperature (deg C)
- Sand (g/m^3)
- Silt (g/m^3)
- Clay (g/m^3)
- NO3-N (g/m^3)
- NH3-N (g/m^3)
- PO4-P (g/m^3)

- TDS (g/m^3)
- Silica-Si (g/m^3)
- Alkalinity as CaCO3 (g/m^3)
- Dissolved Oxygen (g/m^3)
- LDOM (g/m^3)
- RDOM (g/m^3)
- LPOM (g/m^3)
- RPOM (g/m^3)
- Indicator Bacteria (E-Coli) ($E6/m^3$ = #/mL = 100/100mL, etc.)

The Swamp Creek HSPF model explicitly simulates (or can simulate) all of these except for the four organic matter quantities: LDOM, RDOM, LPOM, RPOM. (Note: at the current time the Swamp Creek model does not include the TDS constituent, and the Silica constituent is not calibrated due to a lack of monitoring data.) The correspondence between HSPF constituents (refractory organic N, P, & C) and the W2 organic matter constituents is unresolved!

5.4.1 Spatial Linkage

All loadings to the Sammamish River from Swamp Creek effectively enter the river at a single location, i.e., the mouth of the creek near Bothell, WA. Since the end of the most downstream reach (RCHRES 401) of the Swamp Creek watershed model corresponds to this location, time series results from HSPF (for all of the required constituents) which represent the downstream outflow from this reach will provide the necessary boundary condition data to be input to CE-QUAL-W2.

5.4.2 Temporal Linkage

HSPF can generate results at any time step which is a multiple of the simulation timestep (i.e., 15 minutes). According to C. DeGasperi (Personal communication, 5/2003), the appropriate time step for the CE-QUAL-W2 model of the Sammamish River is one hour. Therefore, the data (flows, temperatures, concentrations) will be one-hour averages.

5.4.3 Linkage Formats

The model linkage output from HSPF will be generated in PLTGEN format, which is easy to to generate and understand. Each PLTGEN file can contain up to 20 time series, so all of the results produced at a boundary location (e.g., a tributary stream model) contributing to CE-QUAL-W2 can be stored in a single file. It is also easy to control the time step, aggregation, and units of the data. Flow will be in units of m^3/s, temperature will be in degrees C, and all WQ constituents will be generated in the form of concentrations (g/m^3) with the possible exception of the indicator bacteria.

5.5 REFERENCES

5.5.1 Water Quality

AQUA TERRA Consultants and HydroQual, Inc. 2001. Modeling Nutrient Loads to Long Island Sound from Connecticut Watersheds, and Impacts of Future Buildout and Management Scenarios. Prepared for Connecticut Department of Environmental Protection, Hartford, CT.

Booth, D.B., J.R.Karr, S. Schauman, C.P.Conrad, S.A. Morley, M.G. Larson, P.C. Henshaw, E.J. Nelson, and S.J. Burges. 2001. Urban Stream Rehabilitation in the Pacific Northwest, Final Report of EPA Grant No. R82-5284-010, University of Washington, Seattle, WA.

Brett, M.T., S.E. Stanley, G.B. Arhonditsis, D.M. Hartley, J.D. Frodge, and D.E. Funke. 2002. Non Point Source Nutrient Impacts on Stream Nutrient Concentrations Along a Forest to Urban Gradient, University of Washington and King County Water and Land Resources, Seattle, WA.

Embrey, S.S., and L.M. Fran. 2003. Surface-Water Quality of the Skokomish, Nooksack, and Green-Duwamish Rivers and Thorton Creek, Puget Sound Basin, Washington, 1995-98: U.S. Geological Survey Water-Resources Investigations Report 02-4190, 199 p.

Fevold, K., C.W. May, H. Berge, and E. Ostergaard. 2001. Habitat Inventory and Assessment of Three Sammamish River Tributaries: North, Swamp, and Little Bear Creeks, King County Department of Natural Resources, Water and Land Resources Division, Seattle, WA.

King County. 1994. Enhanced Reconnaisance of the Eastern Tributaries of the Lower Green River Basin: Data, Analyses, and Management Recommendations, King County Basin Planning Program, Department of Public Works, Seattle, WA.

Nelson, E.J., D.B. Booth, 2002. Sediment Sources in an Urbanizing Mixed Land-Use Watershed. Journal of Hydrology 264: 51-68.

Prych, E. A., and R. N. Brenner. 1983. Effects of Land Use on Discharge and Water Quality in Newaukum Creek Basin, King County, Washington. August 1983, U.S. Geological Survey, and Municipality of Metropolitan Seattle, Seattle WA.